JOURNAL OF AGRICULTURAL RESEARCH
DEPARTMENT OF AGRICULTURE

VOL. II WASHINGTON, D. C., SEPTEMBER 21, 1914 No. 6

# BIRDS AS CARRIERS OF THE CHESTNUT-BLIGHT FUNGUS[1]

By F. D. HEALD and R. A. STUDHALTER,
*Agents, Office of Investigations in Forest Pathology, Bureau of Plant Industry*

## INTRODUCTION

Various writers have expressed the opinion that birds play a part in the dissemination of the chestnut-blight fungus, *Endothia parasitica* (Murr.) And. Since most of these statements were not based on any published investigations, the work described in this paper (6)[2] was undertaken in order to furnish positive evidence as to whether birds actually do carry spores of this fungus.

Birds do not seem to have been extensively accused of spreading plant diseases. Evidence has been presented by Waite (15) that pear-blight is disseminated by humming birds. The same writer (16) also gives a brief statement of the part played by sapsuckers and brings out the probability of long-distance distribution of blight germs by birds. It has been stated (7) that the organism causing the olive-knot disease is carried by birds. Johnston (8) has expressed the belief, based upon some experiments which he conducted, that turkey buzzards are instrumental in spreading the bud-rot of the coconut. In all of these instances the causal organisms are bacteria. Only a single reference has come to our attention in which birds have been charged with spreading fungous diseases, except in the case of the chestnut blight, as will be stated later. In a consideration of the die-back (Naemospora) of peaches, Massee (10, p. 449) says that "probably the conidia are conveyed on the feet of birds from diseased to healthy shoots."

## HISTORICAL REVIEW

The first article published by Murrill (13) on chestnut blight refers to the possible relation of birds to the dissemination of the disease, as follows: "And from these numerous yellowish brown pustules millions of

[1] Investigations conducted in cooperation with the Pennsylvania Chestnut Tree Blight Commission.
[2] Bibliographic citations in parentheses refer to "Literature cited," pp. 421–422.

minute summer spores emerge from day to day in elongated reddish brown masses to be disseminated by the wind and other agencies, such as insects, birds, squirrels, etc." The same author also says (13) "every bird and insect that rests upon an infected spot is liable to carry the spores upon its feet or body to other trees." A few years later Mickleborough (12) mentions birds as carriers of spores of the blight fungus. He says "the minute spores are carried by wind, on the feathers of birds, and the fur of squirrels." Still later Metcalf and Collins (11) say that "there is strong evidence that the spores are spread extensively by birds, especially woodpeckers." Various writers have mentioned the fact that woodpeckers frequent chestnut trees in search of insects. Fulton (2) states in a report on field work done at Orbisonia, Pa., by Mr. R. C. Walton that "woodpecker work was noted in about one-tenth of the oldest lesions," but he offers no conjecture as to the part played by birds in the dissemination of the disease.

Stewart (14) says that "undoubtedly the spores are carried long distances by birds, especially woodpeckers, which visit the diseased trees, seeking borers, in the tunnels of which most of the infections occur." This statement is based on the report of Metcalf and Collins previously referred to and is discredited by Fisher (1), who brings out the point that this and similar statements are not based on positive evidence.

Kittredge (9) reports that field observations at Petersham, Mass., indicate "that birds may be a very important, if not the primary agent," in the distribution of the blight fungus. He is led to this conclusion from the greater number of infections near the borders of coniferous woods, where, he says, birds are more abundant, and from the much larger number of lesions in the middle third of the trunk, which he attributes to the work of creepers, nuthatches, and woodpeckers.

There are numerous popular articles which also accuse birds of being instrumental in the spread of the blight, but these, as well as the statements already quoted, are based entirely on circumstantial evidence.

The first serious attempt to determine whether birds actually do carry the spores of the chestnut-blight fungus was made by the field pathologists of the Pennsylvania Chestnut Tree Blight Commission during the summer of 1912. Since only negative results were obtained, it may be well to quote their statement giving the method employed:

> Birds found on the infected parts of trees were shot during the summer, and their feet, bills, and tail feathers washed separately in sterile water. This water was then centrifuged to bring down the spores that might have been washed from the birds. Part of the sediment was then examined under the microscope and the other part plated out in dilution plates. When colonies of fungi appeared, they were isolated to determine whether they were Diaporthe.

The above description is not sufficiently detailed to make possible an accurate judgment as to whether the negative results obtained were due to

imperfect technique, but our experience leads us to believe that such may have been the case. Plates heavily seeded with bacteria and various fungi give no accurate or reliable results, since the colonies of the chestnut-blight fungus are very slow growing and would be overrun before they had reached sufficient size to be visible to the naked eye. Pycnospore colonies of this fungus at ordinary laboratory temperatures are barely large enough to mark at the end of four days and so would be entirely overlooked in plates crowded with bacteria and other fungi (3).

The negative results reported were based upon analyses of the following: Downy woodpeckers, 8; creepers (kind not specified), 3; hairy woodpeckers, 2; flickers, 4; bluejays, 3; total, 20.

## METHOD USED IN EXPERIMENTS

Nearly all the birds tested by the writers were shot [1] either at Martic Forge or at West Chester, Pa., or in the vicinity of these places, in order that use could be made of the rainfall and temperature records which were kept at these stations. The birds from Martic Forge were shot in or near a 300-acre orchard of badly diseased Paragon trees grafted on native stock. Those from West Chester were taken in the main from a young coppice growth which is practically 100 per cent diseased.

Most of the birds were shot from diseased trees, and in many cases they were working on cankers at the time of shooting or had been seen on chestnut-blight lesions a few minutes before they were killed. They were immediately placed in sterile paper sacks for transport to the laboratory at the University of Pennsylvania.

In the laboratory the procedure was, first, to sterilize a moist chamber in a Lautenschläger sterilizer for 35 minutes at 150° C. A stiff bristle brush was also sterilized in boiling water for half an hour or more. Before beginning work in the culture room the hands and arms of the operator were washed with soap and water and then in mercuric-chlorid solution (1 to 1,000).

When the moist chamber had cooled to room temperature, a flask containing 100 c. c. of sterile tap water was emptied into it. The bird to be tested was held in one hand and the feet, wing, and tail feathers and the head and the bill scrubbed vigorously with the brush, the operation being carried out so that only the parts scrubbed were permitted to come in contact with the wash water. The moist chamber was then well shaken, so as to secure a uniform suspension, and 1 c. c. of the wash water was transferred with a sterile pipette to a second flask containing 99 c. c. of sterile tap water. With a second sterile pipette 1 c. c. or fractions were transferred from the second flask, which had also been well shaken, to each of a series of Petri dishes. The dilutions used varied

[1] The birds used in this work were shot by Mr. C. E. Taylor, formerly in the employ of the Pennsylvania Chestnut Tree Blight Commission, who also centrifuged the wash water for its sediment.

somewhat, but the following were found to give the most satisfactory results:

1 c. c. from second flask to each of 2 Petri dishes.
10 drops from second flask to each of 4 Petri dishes.
5 drops from second flask to each of 4 or 6 Petri dishes.
1 drop from second flask to each of 4 Petri dishes.

In this way the number of plates per bird ranged from 12 to 20 in all cases, except bird No. 1. The number of drops delivered per cubic centimeter by the pipette were counted each time and were found to be fairly constant for any single pipette, although they varied from 24 to 53 drops for the different ones used. A tube of melted 3 per cent dextrose agar plus 10, which had been previously cooled to from 42 to 45° C., was added to each Petri dish and the plates rotated, so as to secure a uniform distribution of the spores. The entire operation of scrubbing and plating was carried out in a culture room, with every precaution against contamination from any source.

The plates were incubated in an inverted position in the laboratory and an attempt was made to keep the temperature of the room as nearly as possible at 25° C. At the end of four days those colonies suspected of being the chestnut-blight fungus were marked with india ink (3). Two or three days later this diagnosis was verified, and all doubtful colonies were transferred to other agar plates, to make certain of their identity. A count was also made of the number of bacterial and yeast colonies, of the number of fungous colonies other than those of *Endothia parasitica*, and of the number of species of fungi represented, as nearly as could be determined from cultural characteristics. With this information and knowing the calibration of the pipette used, it was an easy matter to compute the total number of viable spores or bacteria carried by each bird.

The original wash water was poured back into the flask and several cubic centimeters of formalin added to inhibit the growth of the spores. At a later time the wash water of those birds yielding positive results was centrifuged in 10 c. c. quantities, the sediments thus obtained thrown together and centrifuged again, so that the entire sediment was concentrated in about 2 c. c. of water. This final sediment was given a thorough microscopic examination, primarily for its pycnospore or ascospore content of *Endothia parasitica* and secondarily for the number and kinds of other fungous spores which it might contain.

## LIST OF BIRDS TESTED

A detailed record of the place and time of shooting of each bird is given below.

The birds tested belonged to nine different species. (See Table I.) One of these, the flicker, gets most of its food from the ground, although, as a rule, it flies into a tree when the person approaching is still a good distance away. Another species, the junco, gets practically all of its

food from the ground; both juncos tested were, however, shot out of infected trees. The golden-crowned kinglet is found mostly among foliage. The six other species, the black-and-white creeper, the brown creeper, downy woodpecker, hairy woodpecker, sapsucker, and white-breasted nuthatch, are birds which are in the habit of creeping or climbing over the bark of the trunk and larger branches. As these were considered the most likely carriers of the spores of the chestnut-blight fungus, nearly all of the birds tested, 32 out of 36, belonged to these species. Particular attention was paid to the movements of the birds at the time of shooting, noting especially whether they were working on cankers or, at least, in blighted trees.

It is not uncommon, as stated before, to find evidence that woodpeckers have been at work in older lesions. An example of this is shown in Plate XXXVIII.

Bird No. 1.—Hairy woodpecker (*Dryobates villosus*). (0.)[1]

Shot at Tyrone, Pa., on December 11, 1912. Received and cultures made on December 12, 1912.

Bird No. 2.—Downy woodpecker (*Dryobates pubescens medianus*). (0.)

Shot at Martic Forge, Pa., at 1.10 p. m., on February 21, 1913, while at work on a canker about 12 feet from the ground. Bird was not killed at once, but fluttered along ground for 8 or 10 feet. Canker on which bird was working showed light-orange stromata, with abundant papillæ that were fairly prominent. Cultures made on February 22, 1913.

Bird No. 3.—Junco (*Junco hyemalis*). (0.)

Shot at Martic Forge, Pa., at 10.30 a. m., on February 28, 1913, from blight-infected chestnut tree. Rain of previous night was 0.36 inch, and the air was still very humid at the time the bird was taken. Plates made on March 1, 1913.

Bird No. 4.—Junco. (10,000.)

Same as Bird No. 3.

Bird No. 5.—Downy woodpecker. (30,000.)

Shot at Martic Forge, Pa., on March 10, 1913, out of a small tulip tree. Had been picking about some large, badly diseased, and dead chestnut trees. Cultures made on March 11, 1913.

Bird No. 6.—Downy woodpecker. (73,333.)

Shot near diseased coppice growth at West Chester, Pa., at 10.30 a. m., on March 19, 1913. Had been working on a small canker. Cultures made on March 19, 1913.

Bird No. 7.—Downy woodpecker. (109,022.)

Shot in diseased coppice growth, West Chester, Pa., at 12.30 p. m., on March 19, 1913. Had been working on a canker. Cultures made on March 19, 1913.

Bird No. 8.—Downy woodpecker. (92,000.)

Shot in diseased coppice growth at West Chester, Pa., at 12.40 p. m., on March 19, 1913. Was on a canker when shot. Received and cultures made on March 19, 1913.

Bird No. 9.—Flicker (*Colaptes auratus luteus*). (0.)

Shot at Martic Forge, Pa., on March 24, 1913. Came from the badly infected wood lot to the west of the orchard and was killed in the orchard. Received and cultures made on March 25, 1913.

[1] The numbers in parentheses, following the names of the birds, represent the number of spores of the chestnut-blight fungus carried, as determined by cultures. See Table I.

Bird No. 10.—Downy woodpecker. (757,074.)

Shot from a chestnut tree at Martic Forge, Pa., at 2 p. m., on March 28, 1913. Had been working on a canker, but was not on a canker when killed. Received and cultures made on March 29, 1913.

Bird No. 11.—Downy woodpecker. (15,625.)

Shot at Martic Forge, Pa., at 11 a. m., on March 31, 1913. Was on a canker on an old chestnut tree (22 inches D. B. H.) when killed. Received and cultures made on April 1, 1913.

Bird No. 12.—Downy woodpecker. (31,111.)

Shot at York Furnace, Pa. (near Martic Forge), at 11 a. m., on April 2, 1913. Had been working around a canker on a large chestnut tree. Received and cultures made on April 3, 1913.

Bird No. 13.—Downy woodpecker. (25,000.)

Shot at York Furnace, Pa., at 11.30 a. m., on April 2, 1913. Was on a canker on a large chestnut tree when killed. Received and cultures made on April 3, 1913.

Bird No. 14.—White-breasted nuthatch (*Sitta carolinensis*). (0).

Shot at York Furnace, Pa., at 1 p. m., on April 2, 1913. Shot out of a chestnut-oak tree; had not been seen on any chestnut trees. Received and cultures made on April 3, 1913.

Bird No. 15.—Downy woodpecker. (0.)

Shot at Martic Forge, Pa., at 10 a. m., on April 3, 1913. Was on chestnut tree when killed; had been drumming on an old tree. Not seen on cankers. Received and cultures made on April 4, 1913.

Bird No. 16.—Brown creeper (*Certhia familiaris americana*). (0.)

Shot at Martic Forge, Pa., at 12.30 p. m., on April 7, 1913, from chestnut tree to the side of which it was clinging. Trunk was apparently sound, and no cankers were visible from the ground. Received and cultures made on April 8, 1913.

Bird No. 17.—Golden-crowned kinglet (*Regulus satrapa*). (6,566.)

Shot at Martic Forge, Pa., at 12.30 p. m., on April 7, 1913, from a hemlock tree. Had been climbing up and down trees; was seen on oaks, but not on chestnut. Received and cultures made on April 8, 1913.

Bird No. 18.—Sapsucker (*Sphyrapicus varius*). (5,000.)

Shot from a hickory tree beyond Broomall, Pa., 9 miles west of Philadelphia, at 4 p. m., on April 10, 1913. Had been visiting cankers on chestnut trees. Received and plated out at 8.30 p. m. on April 10, 1913.

Bird No. 19.—White-breasted nuthatch. (5,655.)

Shot out of a chestnut tree beyond Broomall, Pa., at 4 p. m., on April 10, 1913. Had been running up and down trunk of chestnut tree and about cankers. Received and plated out at 8.30 p. m. on April 10, 1913.

Bird No. 20.—Downy woodpecker. (0.)

Shot out of a small dogwood tree about 5 miles west of Philadelphia, Pa., at 4 p. m., on April 10, 1913. Had been working around cankers. Received and plated out at 8.30 p. m. on April 10, 1913.

Bird No. 21.—Downy woodpecker. (5,780.)

Shot out of a soft-maple tree, 2 rods west of orchard at Martic Forge, Pa., on April 15, 1913. Had not been seen on or about any chestnut trees. Received and plated out on April 16, 1913.

Bird No. 22.—Sapsucker. (7,502.)

Shot out of a chestnut tree in a small grove immediately west of blighted orchard at Martic Forge, Pa., at 3.05 p. m., on April 17, 1913. Received and cultures made on April 18, 1913.

Bird No. 23.—Brown creeper. (254,019.)

Shot out of a black oak tree in woods north of coppice growth at West Chester, Pa., on April 18, 1913. Had not been seen on or about chestnut trees. Received and plated out on April 19, 1913.

Bird No. 24.—Black-and-white creeper (*Mniotilta varia*). (o.)

Shot out of a dogwood tree at Martic Forge, Pa., at 10.40 a. m., on April 21, 1913. Had been running up and down a chestnut tree, but was not seen on any cankers. Received and plated out on April 22, 1913.

Bird No. 25.—Downy woodpecker. (27,108.)

Shot while on a canker on a chestnut tree at West Chester, Pa., at 10.30 a. m., on April 25, 1913. Received and plated out on April 26, 1913.

Bird No. 26—Downy woodpecker. (59,742.)

Shot just east of chestnut orchard in a sprout growth of chestnut and oak at Martic Forge, Pa., at 12 m., on April 30, 1913. Had not been seen on or about cankers. Received and plated out on May 1, 1913.

Bird No. 27.—Downy woodpecker. (624,341.)

Shot just east of chestnut orchard from a canker in sprout growth at Martic Forge, Pa., at 12 m., on April 30, 1913. Received and plated out on May 1, 1913.

Bird No. 28.—Black-and-white creeper. (o.)

Shot out of a chestnut oak tree in woods north of sprout growth at West Chester, Pa., at 2.20 p. m., on May 2, 1913. Was not seen on or about any chestnut trees. Received and plated out on May 3, 1913.

Bird No. 29.—Hairy woodpecker. (o.)

Shot out of chestnut tree west of badly infected coppice at West Chester, Pa., on May 2, 1913. Was not positively seen on or about cankers. Received and plated out on May 3, 1913.

Bird No. 30.—Black-and-white creeper. (o.)

Shot in sprout growth of chestnut and oak east of the chestnut orchard at Martic Forge, Pa., at 10.15 a. m., on May 5, 1913. Was not seen on or about cankers. Received and plated out on May 6, 1913.

Bird No. 31.—Black-and-white creeper. (o.)

Shot from a badly diseased chestnut tree in sprout growth east of orchard at Martic Forge, Pa., at 11 a. m., on May 5, 1913. Was not seen on or about cankers. Received and plated out on May 6, 1913.

Bird No. 32.—Black-and-white creeper. (o.)

Shot in timber just west of orchard at Martic Forge, Pa., at 12.30 p. m., on May 5, 1913. Had been seen on chestnut trees, but not about cankers. Received and plated out on May 6, 1913.

Bird No. 33.—Downy woodpecker. (36, 312.)

Shot in wood lot east of coppice at West Chester, Pa., at 10 a. m., on May 9, 1913. Probably was on a canker when shot, but was too high up for this to be positively determined. Received and plated out on May 9, 1913.

Bird No. 34.—Black-and-white creeper. (o.)

Shot out of a diseased chestnut tree about which it had been creeping, north of diseased coppice at West Chester, Pa., at 10.30 a. m., on May 9, 1913. Received and plated out on May 9, 1913.

Bird No. 35.—Hairy woodpecker. (o.)

Shot from a dead chestnut stub west of diseased coppice at West Chester, Pa., at 12.55 p. m., on May 9, 1913. Was not seen on or about any cankers. Received and plated out on May 9, 1913.

Bird No. 36.—Black-and-white creeper. (o.)

Shot in orchard at Martic Forge at 10.30 a. m., on May 12, 1913. Had been creeping over a small canker. Received and plated out on May 13, 1913.

## RESULTS OF TESTS AS SHOWN BY CULTURES

The results obtained from the cultures are given in Table I.

Of the 36 birds tested 19 were found to be carrying spores of the chestnut-blight fungus. The highest positive results were obtained from two downy woodpeckers, which were found to be carrying 757,074 and 624,341 viable spores of *Endothia parasitica*. The next highest was a brown creeper, with 254,019 spores. In each case where the number of colonies of *Endothia parasitica* was very large, there was only a relatively small number of other fungous colonies present. This is best shown in bird No. 10, which yielded almost 14 times as many colonies of the chestnut-blight fungus as of all other fungi. Another good example, although not quite as striking, is bird No. 23, where the proportion was 5 to 1. Part of the plate cultures from bird No. 23 were photographed at the end of nine days (Pl. XXXIX). These show the characteristic development of *Endothia parasitica* colonies on dextrose agar and also the relatively small number of other fungous colonies present.

Positive results were obtained from one of the two juncos tested. Although this species is primarily ground-frequenting in habit, both juncos were shot from blight-infected trees. There are, therefore, two possible sources for the 10,000 spores of the chestnut-blight fungus carried by bird No. 4. First, the blighted tree from which it was shot; second, the pycnospores which had been washed into the soil around the bases of infected trees and which have been found to remain viable for a period of 2 to 13 days of dry weather (5).

In those cases in which the birds were shot directly from a chestnut-blight canker it might be suggested that the spores carried were scattered by the impact of the shot and lodged upon the feathers, and so were not obtained during the normal movements. A brief consideration of the tests of birds giving positive results will throw definite light on this subject.

Of the 19 birds yielding positive results only 6 were on cankers when killed, and positive results were also obtained from 6 of the 8 birds which had been working on cankers just previous to shooting, but which were not on cankers when killed. Again, 7 birds of the 20 which were not seen on cankers at all yielded positive results.

Of the 4 birds yielding the highest numbers of spores of the chestnut blight fungus, only 1, No. 27, was on a canker when shot; 2, Nos. 7 and 10, were not on cankers when shot but had been working on some previous to being killed; while 1, No. 23, had never been seen on a canker.

These results point clearly to the fact that the impact of the shot was not responsible for the presence or any increase in number of blight spores upon the bodies of the birds.

It will be noted that the number of bacterial and yeast colonies was quite large in most instances. The plates from five birds were so heavily

seeded with bacteria that it was impossible to get a reliable count of the number of fungous colonies, or even a test of the presence of colonies of *Endothia parasitica*. In most instances, however, the bacteria caused little or no trouble.

TABLE I.—*Results of tests of birds Nos. 1 to 36 as fungus carriers as shown by cultures*

| No. | Date. | Locality where shot (Pennsylvania). | Kind of bird. | Number of cultures. | Number of bacteria and yeasts. | Total number of fungous colonies. | Number of Endothia parasitica colonies. | Number of fungous species not Endothia parasitica. |
|---|---|---|---|---|---|---|---|---|
| 1 | 1912. Dec. 11 | Tyrone..... | Hairy woodpecker. | 6 | ..... | ..... | ..... | ..... |
| 2 | 1913. Feb. 21 | Martic Forge.. | Downy woodpecker. | 18 | 7,600,000 | 156,600 | 0 | 12 |
| 3 | Feb. 28 | .....do..... | Junco..... | 12 | 1,800,000 | 80,000 | 0 | 9 |
| 4 | ...do..... | .....do..... | .....do..... | 12 | 56,500 | 125,000 | 10,000 | 14 |
| 5 | Mar. 10 | .....do..... | Downy woodpecker. | 18 | 62,500 | 642,500 | 30,000 | 10 |
| 6 | Mar. 19 | West Chester.. | .....do..... | 12 | 950,000 | 173,333 | 73,333 | 6 |
| 7 | ...do..... | .....do..... | .....do..... | 12 | 127,819 | 173,048 | 109,022 | 7 |
| 8 | ...do..... | .....do..... | .....do..... | 12 | 76,000 | 328,000 | 92,000 | 10 |
| 9 | Mar. 24 | Martic Forge.. | Flicker..... | 12 | 12,910,000 | 60,000 | 0 | 12 |
| 10 | Mar. 28 | .....do..... | Downy woodpecker. | 18 | 69,827 | 812,164 | 757,074 | 6 |
| 11 | Mar. 31 | .....do..... | Downy woodpecker. | 18 | 190,625 | 262,500 | 15,625 | 11 |
| 12 | Apr. 2 | York Furnace. | .....do..... | 12 | 2,964,444 | 444,444 | 31,111 | 6 |
| 13 | ...do..... | .....do..... | .....do..... | 12 | 18,300,000 | 285,000 | 25,000 | 7 |
| 14 | ...do..... | .....do..... | White-breasted nuthatch. | 12 | 225,000 | 90,000 | 0 | 6 |
| 15 | Apr. 4 | Martic Forge.. | Downy woodpecker. | 12 | (a) | (a) | (a) | (a) |
| 16 | Apr. 7 | .....do..... | Brown creeper. | 12 | 40,000 | 80,000 | 0 | 5 |
| 17 | ...do..... | .....do..... | Golden-crowned kinglet. | 12 | 32,849 | 85,357 | 6,566 | 5 |
| 18 | Apr. 10 | 9 miles west of Philadelphia. | Sapsucker..... | 12 | 170,000 | 145,000 | 5,000 | 9 |
| 19 | ...do..... | .....do..... | White-breasted nuthatch. | 12 | 96,045 | 33,900 | 5,655 | 4 |
| 20 | ...do..... | 5 miles west of Philadelphia. | Downy woodpecker. | 12 | 130,000 | 130,000 | 0 | 8 |
| 21 | Apr. 15 | Martic Forge.. | .....do..... | 12 | 3,740,000 | 121,387 | 5,780 | 6 |
| 22 | Apr. 17 | .....do..... | Sapsucker..... | 12 | 544,936 | 337,584 | 7,502 | 9 |
| 23 | Apr. 18 | West Chester.. | Brown creeper. | 14 | 102,309 | 304,004 | 254,079 | 6 |
| 24 | Apr. 21 | Martic Forge.. | Black-and-white creeper. | 14 | 14,925,000 | 90,000 | 0 | 4 |
| 25 | Apr. 25 | .....do..... | Downy woodpecker. | 16 | 358,437 | 159,638 | 27,108 | 9 |
| 26 | Apr. 30 | Martic Forge.. | .....do..... | 14 | 64,338 | 657,169 | 59,742 | 8 |
| 27 | ...do..... | .....do..... | .....do..... | 14 | 6,127,951 | 970,731 | 624,341 | 4 |
| 28 | May 2 | West Chester.. | Black-and-white creeper. | 14 | 478,571 | 28,581 | 0 | 1 |
| 29 | ...do..... | .....do..... | Hairy woodpecker. | 14 | (a) | (a) | (a) | (a) |
| 30 | May 5 | Martic Forge.. | Black-and-white creeper. | 16 | (a) | (a) | (a) | (a) |
| 31 | ...do..... | .....do..... | .....do..... | 16 | (a) | (a) | (a) | (a) |
| 32 | ...do..... | .....do..... | .....do..... | 16 | (a) | (a) | (a) | (a) |
| 33 | May 9 | West Chester.. | Downy woodpecker. | 16 | 1,893,854 | 64,245 | 36,312 | 5 |
| 34 | ...do..... | .....do..... | Black-and-white creeper. | 16 | 18,181 | 28,571 | 0 | 5 |
| 35 | ...do..... | .....do..... | Hairy woodpecker. | 20 | 172,413 | 51,724 | 0 | 5 |
| 36 | May 12 | Martic Forge.. | Black-and-white creeper. | 16 | 24,000 | 16,000 | 0 | 4 |

a Discarded; too heavily seeded with bacteria for a reliable test.

TABLE I.—*Results of tests of birds Nos. 1 to 36 as fungus carriers as shown by cultures*—Continued

SUMMARY

| No. | Kind of bird. | Number tested. | Number carrying Endothia parasitica spores. | Maximum number of spores of Endothia parasitica carried by single bird. |
|---|---|---|---|---|
| 1 | Black-and-white creeper | 7 | 0 | 0 |
| 2 | Brown creeper | 2 | 1 | 234,019 |
| 3 | Downy woodpecker | 16 | 13 | 757,074 |
| 4 | Flicker | 1 | 0 | 0 |
| 5 | Golden-crowned kinglet | 1 | 1 | 6,566 |
| 6 | Hairy woodpecker | 3 | 0 | 0 |
| 7 | Junco | 2 | 1 | 10,000 |
| 8 | White-breasted nuthatch | 2 | 1 | 5,055 |
| 9 | Sapsucker | 2 | 2 | 7,502 |
| | Total | 36 | 19 | |

## RELATION OF RAINFALL TO BIRDS AS CARRIERS OF THE CHESTNUT-BLIGHT FUNGUS

The highest positive results were invariably obtained soon after a period of heavy rainfall, generally one extending over several days. (See Table II.) During the time covered by our tests there were four such rains. (See Table III.) Birds shot from two to four days after each period were found to be carrying the highest numbers of spores of *Endothia parasitica*. Some of the birds shot at other times were also found to be carrying spores of the chestnut-blight fungus, but in much smaller numbers. This relation between the high number of spores and the periods of rainfall is explained by the fact that the pycnospores of the chestnut-blight fungus are produced in large numbers during and after rains and are washed down the trunks of the trees (4). This is explained more in detail later.

TABLE II.—*Rainfall related to birds as carriers of the chestnut-blight fungus*

| Rainfall in inches. | | | | No. of bird. | Locality where shot (Pennsylvania). | Date killed. | Number of Endothia parasitica spores. | Number of fungous spores not Endothia parasitica. |
|---|---|---|---|---|---|---|---|---|
| Date. | West Chester, Pa. | Date. | Martic Forge, Pa. | | | | | |
| 1913. | | 1913. | | | | 1913. | | |
| Feb. 21 | 0.19 | Feb. 22 | 0.09 | 2 | Martic Forge | Feb. 21 | 0 | 156,600 |
| Feb. 22 | .07 | | | | | | | |
| Feb. 27 | .78 | Feb. 27 | .36 | 3 | do | Feb. 28 | 0 | 80,000 |
| | | Mar. 5 | .02 | 4 | do | Feb. 28 | 10,000 | 115,000 |
| Mar. 9 | .03 | | | 5 | do | Mar. 10 | 30,000 | 612,500 |
| Mar. 10 | .53 | Mar. 10 | .55 | 6 | West Chester | Mar. 19 | 73,333 | 100,000 |
| | | Mar. 13 | 1.29 | | | | | |
| Mar. 13 to Mar. 15 | 1.38 | Mar. 15 | .92 | 7 | do | Mar. 19 | 109,022 | 64,626 |
| | | | | 8 | do | Mar. 19 | 92,000 | 236,000 |
| Mar. 21 | 1.64 | Mar. 21 | .62 | | | | | |
| Mar. 26 | 1.18 | Mar. 26 | 3.47 | 9 | Martic Forge | Mar. 24 | 0 | 60,000 |
| Mar. 27 | | | | | | | | |
| | | | | 10 | do | Mar. 29 | 757,074 | 55,090 |
| Mar. 30 | .30 | Mar. 31 | .04 | 11 | do | Mar. 31 | 15,625 | 246,875 |
| Mar. 31 | .20 | | | | | | | |

TABLE II.—*Rainfall related to birds as carriers of the chestnut-blight fungus*—Continued

| Rainfall in inches. | | | | No. of bird. | Locality where shot (Pennsylvania). | Date killed. | Number of Endothia parasitica spores. | Number of fungus spores not Endothia parasitica. |
|---|---|---|---|---|---|---|---|---|
| Date. | West Chester, Pa. | Date. | Martic Forge, Pa. | | | | | |
| 1913. | | 1913. | | | | 1913. | | |
| ..... | ..... | Apr. 2 | 0.10 | 12 | York Furnace..... | Apr. 2 | 31,111 | 413,333 |
| ..... | ..... | ..... | ..... | 13 | .....do..... | Apr. 2 | 25,000 | 260,000 |
| ..... | ..... | ..... | ..... | 14 | .....do..... | Apr. 2 | 0 | 90,000 |
| Apr. 4 | .56 | Apr. 4 | .23 | 15 | Martic Forge..... | Apr. 4 | 0 | 0 |
| ..... | ..... | ..... | ..... | 16 | .....do..... | Apr. 7 | 0 | 80,000 |
| ..... | ..... | ..... | ..... | 17 | .....do..... | Apr. 7 | 6,566 | 78,691 |
| ..... | ..... | ..... | ..... | 18 | West of Philadelphia..... | Apr. 10 | 5,000 | 140,000 |
| Apr. 10 to Apr. 13 | 2.49 | Apr. 11 | .55 | 19 | .....do..... | Apr. 10 | 5,655 | 28,245 |
| ..... | ..... | Apr. 15 | 1.23 | 20 | .....do..... | Apr. 10 | 0 | 130,000 |
| Apr. 13 to Apr. 16 | 1.57 | Apr. 16 | 1.15 | 21 | Martic Forge..... | Apr. 15 | 5,780 | 115,607 |
| ..... | ..... | ..... | ..... | 22 | .....do..... | Apr. 17 | 7,502 | 330,082 |
| ..... | ..... | ..... | ..... | 23 | West Chester..... | Apr. 18 | 254,019 | 49,985 |
| ..... | ..... | ..... | ..... | 24 | Martic Forge..... | Apr. 21 | 0 | 90,000 |
| ..... | ..... | ..... | ..... | 25 | West Chester..... | Apr. 25 | 27,108 | 132,530 |
| Apr. 28 Apr. 29 | 2.43 | Apr. 28 | 2.33 | 26 | Martic Forge..... | Apr. 30 | 59,742 | 597,427 |
| Apr. 29 | .11 | Apr. 29 | .07 | 27 | .....do..... | Apr. 30 | 624,341 | 346,390 |
| ..... | ..... | ..... | ..... | 28 | West Chester..... | May 2 | 0 | 28,581 |
| ..... | ..... | ..... | ..... | 29 | .....do..... | May 2 | ..... | ..... |
| ..... | ..... | ..... | ..... | 30 | Martic Forge..... | May 5 | ..... | ..... |
| ..... | ..... | ..... | ..... | 31 | .....do..... | May 5 | ..... | ..... |
| ..... | ..... | ..... | ..... | 32 | .....do..... | May 5 | ..... | ..... |
| ..... | ..... | ..... | ..... | 33 | West Chester..... | May 9 | 36,312 | 27,933 |
| ..... | ..... | ..... | ..... | 34 | .....do..... | May 9 | 0 | 28,571 |
| ..... | ..... | ..... | ..... | 35 | .....do..... | May 9 | 0 | 57,724 |
| ..... | ..... | ..... | ..... | 36 | Martic Forge..... | May 12 | 0 | 16,000 |

TABLE III.—*Relation of maximum number of spores of the chestnut-blight fungus carried to periods of maximum rainfall*

| Rainfall in inches. | | | | Date bird was shot. | Locality where bird was shot (Pennsylvania). | Number of spores of Endothia parasitica carried. |
|---|---|---|---|---|---|---|
| Date. | West Chester, Pa. | Date. | Martic Forge, Pa. | | | |
| 1913. | | 1913. | | 1913. | | |
| Mar. 10 | 0.53 | Mar. 10 | 0.55 | ..... | ..... | ..... |
| Mar. 13 to Mar. 15 | 1.38 | Mar. 13 | 1.29 | ..... | ..... | ..... |
| | | Mar. 15 | .92 | ..... | ..... | ..... |
| ..... | ..... | ..... | ..... | Mar. 19 | West Chester..... | 73,333 |
| ..... | ..... | ..... | ..... | Mar. 19 | .....do..... | 109,022 |
| ..... | ..... | ..... | ..... | Mar. 19 | .....do..... | 90,000 |
| Mar. 26 to Mar. 27 | 1.18 | Mar. 26 | 3.47 | ..... | ..... | ..... |
| ..... | ..... | ..... | ..... | Mar. 29 | Martic Forge..... | 757,974 |
| Apr. 10 to Apr. 13 | 2.49 | Apr. 11 | .55 | ..... | ..... | ..... |
| Apr. 13 to Apr. 16 | 1.57 | Apr. 15 | 1.23 | ..... | ..... | ..... |
| | | Apr. 16 | 1.15 | ..... | ..... | ..... |
| ..... | ..... | ..... | ..... | Apr. 18 | West Chester..... | 254,019 |
| Apr. 27 to Apr. 28 | 2.43 | Apr. 28 | 2.33 | ..... | ..... | ..... |
| ..... | ..... | ..... | ..... | Apr. 30 | Martic Forge..... | 59,742 |
| ..... | ..... | ..... | ..... | Apr. 3 | .....do..... | 624,341 |

## MICROSCOPIC EXAMINATION OF CENTRIFUGED SEDIMENTS

The sediments from those birds yielding positive results were given a thorough microscopic examination, primarily to ascertain whether the birds were carrying pycnospores or ascospores. (See Table IV.) Ascospores were not found to be present in a single instance. However, in sediments from birds yielding high positive results pycnospores could be found very easily. Where the positive results were not so high, pycnospores were located with more difficulty, but could be found in all sediments except those from birds showing by cultures the smallest number of spores of the blight fungus. The results from cultures substantiate the microscopic examinations, since the rate of development of colonies of the chestnut-blight fungus always indicated their origin from pycnospores (3).

TABLE IV.—*Results of microscopic examination of centrifuged sediments of birds Nos. 1 to 36*

| Bird No. | Number of spores of Endothia parasitica carried, as shown by cultures. | Kind of spores shown by microscopic examination. | Bird No. | Number of spores of Endothia parasitica carried, as shown by cultures. | Kind of spores shown by microcopic examination. |
|---|---|---|---|---|---|
| 1.... | 0 | Examination not necessary. | 20.... | 0 | Examination not necessary. |
| 2.... | 0 | Do. | 21.... | 5,780 | No ascospores. |
| 3.... | 0 | Do. | 22.... | 7,502 | Do. |
| 4.... | 10,000 | No ascospores. | 23.... | 254,019 | No ascospores; pycnospores fairly abundant. |
| 5.... | 30,000 | No ascospores; pycnospores present. | 24.... | 0 | Examination not necessary. |
| 6.... | 73,333 | Do. | 25.... | 27,108 | No ascospores; pycnospores present. |
| 7.... | 109,022 | Do. | | | |
| 8.... | 92,000 | Do. | 26.... | 59,742 | Do. |
| 9.... | 0 | Examination not necessary. | 27.... | 624,341 | No ascospores; pycnospores fairly abundant. |
| 10.... | 757,074 | No ascospores; pycnospores abundant. | 28.... | 0 | Examination not necessary. |
| 11.... | 15,625 | No ascospores; pycnospores present. | 29.... | 0 | Do. |
| | | | 30.... | 0 | Do. |
| 12.... | 31,111 | Do. | 31.... | 0 | Do. |
| 13.... | 25,000 | Do. | 32.... | 0 | Do. |
| 14.... | 0 | Examination not necessary. | 33.... | 36,312 | No ascospores; pycnospores present. |
| 15.... | 0 | Do. | | | |
| 16.... | 0 | Do. | 34.... | 0 | Examination not necessary. |
| 17.... | 6,566 | No ascospores. | 35.... | 0 | Do. |
| 18.... | 5,000 | Do. | 36.... | 0 | Do. |
| 19.... | 5,655 | Do. | | | |

During the time covered by our analyses there were five periods during which ascospores were expelled in the field—i. e., on March 20 and 21, 26 and 27, April 4 and 5, 13 to 16, 27 to 29. On these days ascospores were ejected at both Martic Forge and West Chester, but only a very few spores were expelled on March 20 and 21 and on April 4 and 5. If the remaining dates are compared with Table III, it will be noticed that the birds yielding the highest positive results were shot just after the rains which produced copious expulsion of ascospores. It might therefore be expected that birds would be carrying these spores as well as pycnospores, but such does not appear to have been the case. Studies on wind dissemination show that ascospores are carried away by the wind upon being shot out

of the perithecia. Other work (4) has shown that ascospores are not washed down the trunks of trees by the rains. The birds, therefore, have little, if any, opportunity of collecting ascospores, unless they happen to be working on a canker at the time when expulsion is taking place.

That the pycnospores were not obtained directly from spore horns is indicated by the fact that these were very rare during the earlier part of the period covered by the tests. Furthermore, the number of spores carried by a single bird was much smaller than would be expected if individual spore horns had been brushed off, since a medium-sized tendril is known to contain millions of pycnospores. We know that pycnospores are washed down the trunks of trees in large numbers even by the winter and spring rains (4). Work done in this laboratory shows that viable pycnospores can be obtained in abundance from the healthy bark below lesions. From the facts cited we are led to the conclusion that the pycnospores carried by the birds are brushed off from either normal or diseased bark, or from both, in the movements of the birds over these surfaces.

## BIRDS AS CARRIERS OF OTHER FUNGI

Results from cultures show that a few of the birds (Nos. 7, 10, 23, 27, and 33) were carrying a greater number of viable spores of the chestnut-blight fungus than of all other species of fungi combined. The reverse, however, was true of all other birds, most of which were found to be carrying fungous spores in large numbers. (See Table II.) The number of species of fungi other than *Endothia parasitica* represented in the cultures varied from 4 to 14 per bird, with an average of 7. (See Table I.) Those met with most frequently were various species of Penicillium, Cladosporium, and Alternaria. Many of the other fungi, which appeared in smaller numbers, were not identified, on account of their failure to fruit in culture.

The microscopic examination of the centrifuged sediments revealed the fact that more species of fungi were carried than was indicated by the cultures. Spores of different species were distinguished by form, size, septation, and coloration. For example, the cultures from bird No. 7 indicated the presence of only 7 species other than *Endothia parasitica*, while the sediment showed at least 12 different kinds of spores. Again, bird No. 23 gave 6 species in cultures and at least 19 by microscopic examination of the sediment. The types of spores found in the sediments of these two birds are illustrated by figures 1 and 2. The actual number of fungous spores carried was beyond doubt greater in every case than is indicated in Table I. The smaller number of species obtained from the cultures was due to the fact that the medium used was not suitable to the growth of some of the spores, or that they grew so slowly that they were overrun by other more rapid-growing forms before they had become visible.

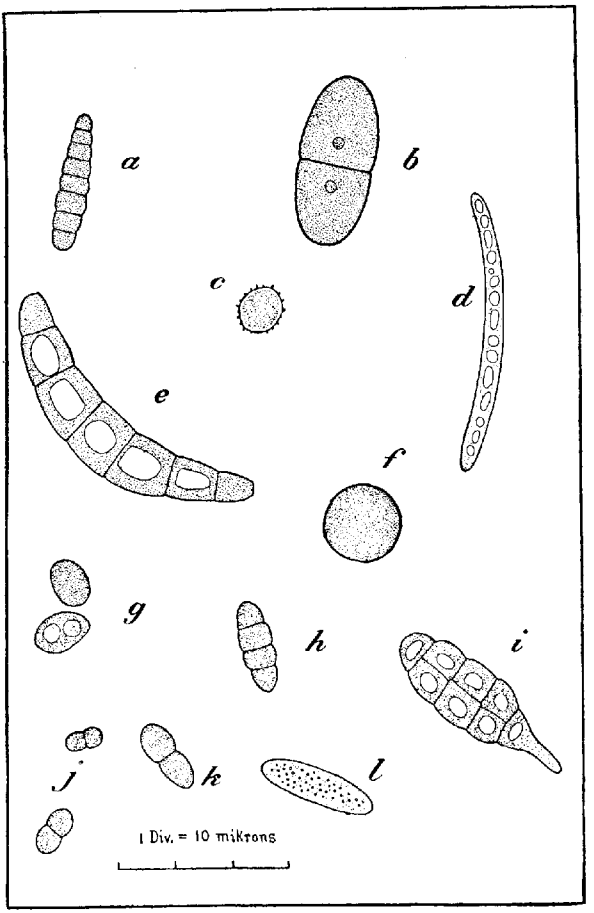



FIG. 1.—Types of spores other than those of *Endothia parasitica* obtained by the microscopic examination of the centrifuged sediment from the test of bird No. 7, a downy woodpecker: *a*, Brown; *b*, dark brown; *c*, brown; *d*, cyanophyceous; *e*, brown; *f*, nearly black; *g*, smoky; *h*, brown; *i*, brown; *j*, brown; *k*, brown; *l*, cyanophyceous.

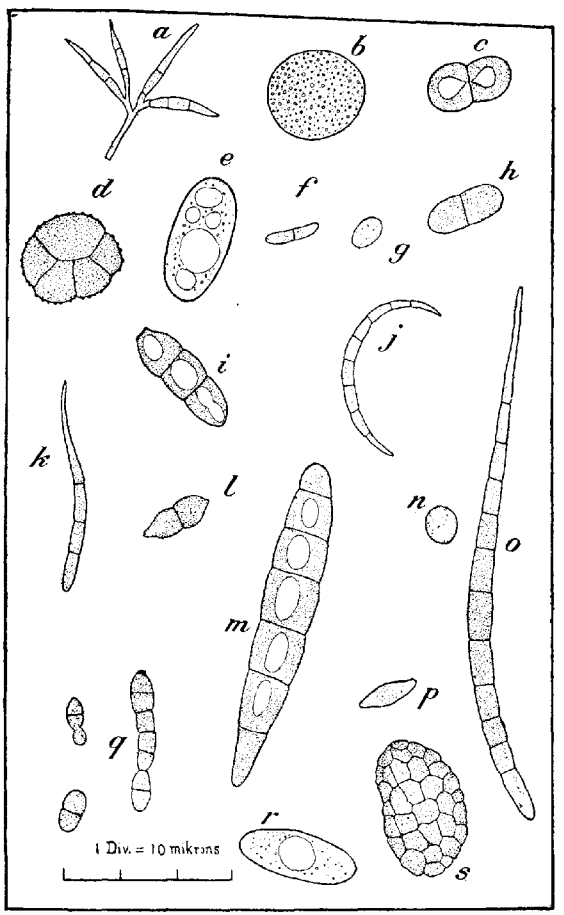



FIG. 2.—Types of spores other than those of *Endothia parasitica* obtained by the microscopic examination of the centrifuged sediment from the test of bird No. 23, a brown creeper. Brown-spored forms appear to predominate: *a*, Hyaline; *b*, hyaline; *c*, dark brown; *d*, nearly black; *e*, hyaline; *f*, light brown; *g*, smoky; *h*, pale smoky; *i*, dark smoky; *j*, hyaline; *k*, pale smoky; *l*, dark smoky; *m*, smoky; *n*, hyaline; *o*, brown; *p*, hyaline; *q*, dark smoky; *r*, hyaline; *s*, very dark, almost black.

No attempt was made to determine whether any of the spores other than those of the chestnut-blight fungus belonged to parasitic species. Judging, however, from the large numbers and kinds of fungous spores carried and from the very high numbers of spores of *Endothia parasitica* obtained at certain times, it is reasonable to suspect that these birds or birds of other species may be important agents in the spread of some other plant diseases, at least under certain favorable conditions. In the light of facts revealed by this investigation it is suggested that birds may play a part in the dissemination of such troubles as the brown-rot of stone fruits, die-back of peaches, plums, and apricots, or of any other diseases where birds may be attracted to the host.

## SUMMARY AND CONCLUSIONS

(1) The 36 birds tested belonged to 9 different species.

(2) Of the 36 birds 32 were those which are in the habit of climbing over the trunk and larger branches of trees.

(3) Most of the birds were shot from blighted chestnut trees; some directly from blight cankers.

(4) The bill, head, feet, tail, and wings of each bird were scrubbed with a brush and poured plates were made from the wash water, which was retained and centrifuged for its sediment.

(5) Of the 36 birds tested, 19 were found to be carrying spores of the chestnut-blight fungus, *Endothia parasitica*.

(6) The viable spores of the chestnut-blight fungus carried by two downy woodpeckers numbered 757,074 and 624,341, respectively, while a brown creeper carried 254,019.

(7) The cultures from some of the birds showed from 2 to 14 times as many viable spores of the chestnut-blight fungus as of all other fungi combined.

(8) The highest positive results were invariably obtained from birds shot from two to four days after a period of considerable rainfall.

(9) The rate of development in cultures always indicated that the colonies of the chestnut-blight fungus originated from pycnospores; pycnospores were generally found in the centrifuged sediments, while ascospores were never detected. The birds were therefore carrying pycnospores only.

(10) The pycnospores carried were probably brushed off from either normal or diseased bark, or from both, in the movements of the birds over these surfaces.

(11) Both the cultures and an examination of the centrifuged sediments showed that the birds were carrying a large number of spores of many species of fungi other than *Endothia parasitica*.

(12) From the above facts the writers are led to the conclusion that birds in general are important carriers of fungous spores, some of which may belong to parasitic species.

(13) Furthermore, many birds which climb or creep over the bark of chestnut trees are important agents in carrying viable pycnospores of the chestnut-blight fungus, especially after a period of considerable rainfall.

(14) Birds are probably not very important agents in spreading the chestnut blight locally, on account of the predominance of other and more important factors of dissemination, as, for example, the wind.

(15) The writers believe, however, that many of the so-called "spot infections" (local centers of infection isolated from the area of general infection) have had their origin from pycnospores carried by migratory birds. Some of the birds tested were not permanent residents of eastern Pennsylvania, but were shot during their migration northward. These, no doubt, carry spores great distances. Each time the bird climbs or creeps over the trunk or limbs of a tree some of the spores may be brushed off and may lodge in crevices or on the rough bark. From this position they may be washed down into wounds by the rain and may thus cause infections.

## LITERATURE CITED


1. FISHER, A. K.
   1912. [Discussion on birds and the chestnut blight.] Penn. Chestnut Blight Conf., Rpt. of Proc., p. 103–105. (Discussed also by F. C. Stewart and S. B. Detwiler.)
2. FULTON, H. R.
   1912. Recent notes on the chestnut bark disease. Penn. Chestnut Blight Conf., Rpt. of Proc., p. 48–56.
3. HEALD, F. D.
   1913. A method of determining in analytic work whether colonies of the chestnut blight fungus originate from pycnospores or ascospores. *In* Mycologia, v. 5, no. 5, p. 274–277, pl. 98–101.
4. ——— and GARDNER, M. W.
   1913. The relative prevalence of pycnospores and ascospores of the chestnut-blight fungus during the winter. *In* Phytopathology, v. 3, no. 6, p. 296–305, pl. 26–28. (Preliminary note *in* Science, n. s., v. 37, p. 916–917. 1913.)
5. ——— ———
   1914. Longevity of pycnospores of the chestnut-blight fungus in soil. *In* Jour. Agr. Research, v. 2, no. 1, p. 67–75.
6. ——— and STUDHALTER, R. A.
   1913. Preliminary note on birds as carriers of the chestnut blight fungus. *In* Science, n. s., v. 38, no. 973, p. 278–280.
7. HORNE, W. T., PARKER, W. B., and DAINES, L. L.
   1912. The method of spreading of the olive knot disease. Abstract. *In* Phytopathology, v. 2, no. 2, p. 96.
8. JOHNSTON, J. R.
   1912. The history and cause of the coconut bud-rot. U. S. Dept. of Agr., Bur. Pl. Ind., Bul. 22, 175 p., 15 pl.
9. KITTREDGE, J.
   1913. Notes on the chestnut bark disease (Diaporthe parasitica, Murrill) in Petersham, Mass. *In* Bul. Harvard Forestry Club, v. 2, p. 13–22.
10. MASSEE, G. E.
    1910. Diseases of cultivated plants and trees. 602 p., illus. New York.

11. METCALF, HAVEN, and COLLINS, J. F.
1911. The control of the chestnut bark disease. U. S. Dept. Agr., Farmers' Bul. 467, 24 p., 5 figs.
12. MICKLEBOROUGH, JOHN.
1909. A report on the chestnut tree blight, the fungus Diaporthe parasitica, Murrill. 16 p., 2 pl. (1 col.). (Published by Penn. Dept. Forestry.)
13. MURRILL, W. A.
1906. A serious chestnut disease. *In* Jour. N. Y. Bot. Gard., v. 7, no. 78, p. 143–153, fig. 13–19.
14. STEWART, F. C.
1912. Can the chestnut bark disease be controlled? Penn. Chestnut Blight Conf., Rpt. of Proc., p. 40–45.
15. WAITE, M. B.
1898. Pear blight and its treatment. (East. N. Y. Hort. Soc., Proc. 2d Ann. Meet.) *In* N. Y. State Agr. Soc., 57th Ann. Rpt., 1897, p. 780, 787.
16. ——
1906. Pear-blight work and its control in California. *In* Rpt. 31st Fruit-Grow. Conv. State Cal., p. 143–144.

PLATE XXXVIII

Old blight canker on chestnut, showing the work of woodpeckers.

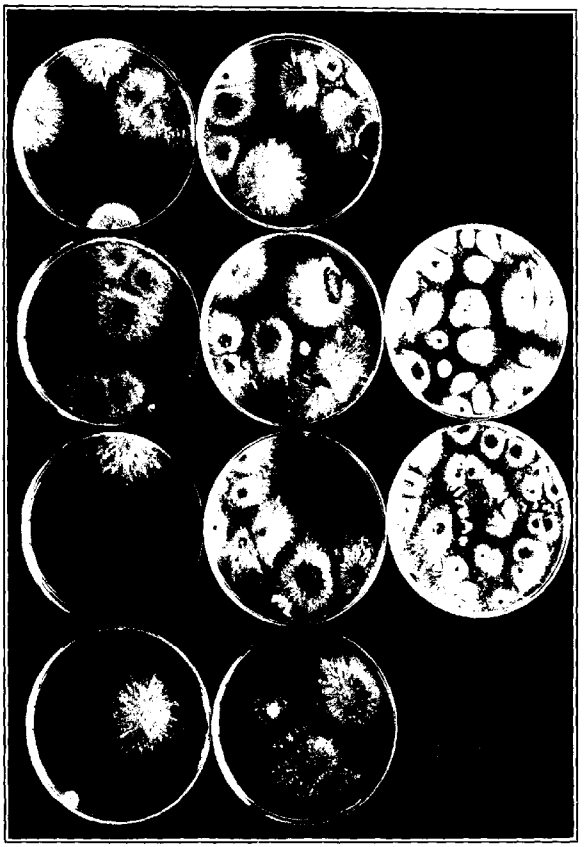


PLATE XXXIX

Series of cultures 9 days old obtained in the test of bird No. 23, a brown creeper. Each Petri dish of the first series (first row) contained 1/10,000 of the water in which the bird was washed; each of the second series (middle row), 1/45,000; and each of the third series (third row), only 1/90,000.

# DENSITY OF WOOD SUBSTANCE AND POROSITY OF WOOD

By FREDERICK DUNLAP,
*Forest Assistant, Forest-Products Laboratory, Forest Service*

## PURPOSE OF THE INVESTIGATION

The investigation the results of which are presented in this paper was made to determine the density of the lignocellulose which makes up the walls of the cells of which wood is composed as a basis for calculating the porosity of wood.[1] The density of a block of wood differs from that of the lignocellulose of which it is built up, because wood is a porous structure and is not a homogeneous solid. Lignocellulose has a density greater than unity and sinks in water; blocks of wood float, especially when dry, because the air they contain buoys them up.

The volume of a block of wood is thus made up of two parts, a framework of lignocellulose and a large number of small cavities inclosed in the former. The cavities may be occupied by a variety of fluids, incrusting materials, and solid substances. The ratio of the sum of the volumes of these cavities to the volume of the entire block is the measure of the porosity of the wood. The volume of the entire block is readily ascertained (by submersion, for example), so that the determination of porosity resolves itself into a determination of the volume of the cavities.

The volume of the cavities may be measured directly by filling them with a fluid of known density; actually such measurements have never met with entire success. The same result can also be reached indirectly by determining the density of the wood substance and then calculating its volume in a block of wood; the difference between the gross volume of the block and the volume of the solid substance is the volume of the cavities.

## RELATION TO TECHNICAL PROBLEMS

If the heat conductivity of wood is greater than that of water, the cavities in wet wood offer an impediment to the flow of heat. If the conductivity of water is greater, the flow of heat is accelerated by its presence in the cavities. Air in the cavities of dry wood will likewise affect heat conductivity. In other words, the conductivity of a block of wood is in part a function of its porosity. The true significance of heat conductivity when measured on blocks of wood can be properly interpreted only when the porosity is known and when the extent to

[1] The research work was carried on at the Forest-Products Laboratory, maintained by the Forest Service in cooperation with the University of Wisconsin, at Madison, Wis.

which observed results depend on wood substance and on air space is calculated. The porosity of wood, then, is an important item in the study of its heat conductivity.

The porosity of wood is also of importance directly in the practice of impregnating wood with preservatives, since the capacity of the cavities fixes an upper limit to the quantity of preservative which may be injected.

## PREVIOUS INVESTIGATIONS

The first published statement of the density of wood substance appears to be that of Hofmeister,[1] who assumed a density of at least 1.45. His assumption was based on measurements of the density of flax fibers, which have a very small lumen. Subsequently other writers assumed a density of 1.55.

In 1879, Sachs[2] published a careful study of the density of wood substance. By washing the air from wood in a current of water and then using Archimedes's method, Sachs obtained a density of 1.5 for *Pinus pumilo* and 1.4 for *Abies pectinata*. Wood boiled in water to expel the air gave somewhat higher densities, and when washed in alcohol the results were still higher—viz, 1.523.

Finally, Sachs suspended thin sections of wood, from 1/10 to 1/5 mm. thick, in solutions of calcium nitrate and zinc nitrate. The density of the solution was adjusted until the sections of wood sank very slowly. It is evident that when the wood remains suspended in the solution the two are of the same density. Sachs read his solution densities from a hydrometer.

Sachs found no difference between determinations made with these two nitrates. He evidently experienced difficulty in reaching exact equilibrium, and was satisfied when his sections sank very slowly through his solutions. He found that sections of *Prunus cerifera* and *Populus dilitata* sank in calcium nitrate solutions of 1.54 density, while *Abies pectinata* sank in a zinc-nitrate solution of 1.56 density. His results were not final, but were merely a somewhat closer approximation than any of his predecessors had secured.

Three years later Hartig[3] determined the density of wood substance for five additional European species—viz, birch, beech, oak, spruce, and Scotch pine. He followed Sachs's method, using calcium nitrate, and apparently met with greater success in establishing equilibrium between his solutions and the wood sections. He found the same value, 1.555, for the density of all five species.

[1] Hofmeister, Wilhelm. Ueber Spannung, Ausflussmenge und Ausflussgeschwindigkeit von Säften lebender Pflanzen. *In* Flora, Jahrg. 45 (n. R. Jahrg. 20), No. 7, p. 105, 1862.

[2] Sachs, Julius. Ueber die Porosität des Holzes. *In* Arb. Bot. Inst. Würsburg, Bd. 2, p. 291–332, 2 fig., 1879.

[3] Hartig, Robert. Ueber die Vertheilung der organischen Substanz, des Wassers und Luftraumes in den Bäumen, und über die Ursache der Wasserbewegung in transpirirenden Pflanzen. 112 p. Berlin, 1882. (Untersuch. Forstbot. Inst. München. Bd. 2.)

## EXPERIMENTAL METHODS AND APPARATUS

The method used in the present research was the same in principle as that followed by Sachs and by Hartig in similar studies on a few European woods 30 years ago. Small blocks were boiled in water until sufficient air was expelled to make them sink. Thin sections were then cut with a sharp knife across the grain. These sections were placed in a solution of calcium nitrate and boiled for a few seconds to complete expulsion of the air; then they were transferred to cold solutions of the same salt. The densities of these cold solutions averaged about 1.6, which was a little greater than the anticipated density of the wood, so that the sections floated on the surface. Water was added, a few drops at a time at intervals of four hours or more, and the solutions held at constant temperature until equilibrium was established and the wood hung suspended in the solution.

A specific-gravity bottle was then submerged in the solution and filled; after a few minutes it was withdrawn, washed, dried, cooled to room temperature, and weighed. The volume of the bottle was determined by filling it with freshly boiled distilled water at the same temperature as the solutions measured, cooling to room temperature, and weighing. These relative densities of the solutions were divided by the density of air-free distilled water at the temperature in question, and a result was obtained expressing the density of the solutions (and also of the wood suspended) in terms of water at its maximum density.

Preliminary experiments showed that accurate results could not be secured without control of the temperature of the solutions. For this purpose a tank 50 cm. on each edge was hung in a wooden box so as to leave a 10-cm. space on four sides and the bottom. This space was filled with sawdust. The tank was open above, but was partially covered with a board when the temperature of the room fell more than 10° C. below the temperature of the water in the tank. A shaft extended through the center of the bottom, and a stirrer made from a 30-cm. electric fan was mounted on this shaft. The stirrer was driven by a ⅛-horsepower electric motor at a speed of 65 revolutions per minute by a belt and through an intermediate shaft for reducing the speed.

The tank was filled nearly full of water. Heat was supplied by a 175-watt carbon filament incandescent lamp submerged in one corner of the tank. The temperature was controlled automatically by an ether thermoregulator—an ether reservoir inverted and sealed with mercury. The recession of the mercury column as the ether contracted broke a dry-cell circuit through a relay and turned on the lamp. A rise in temperature beyond a certain point extinguished the lamp. In this way the temperature of the water in the tank was kept within a range of ½ degree centigrade.

The solutions used were placed in wide-mouthed salt bottles of 150 c. c. capacity and supported in trays, with the water rising to their necks.

## SELECTION AND PREPARATION OF THE MATERIAL

The wood used was taken from material on hand at the Forest-Products Laboratory. The species selected were those studied in investigating the specific heat of wood. The use of the same species in the determination of heat conductivity will result in a series of exactly comparable results.[1]

Table I gives the woods used and the source and nature of each species.

TABLE I.—*Species of woods used in tests, giving nature and source of material*

| Species. | Heartwood or sapwood. | Number of rings per inch. | Locality where grown. |
|---|---|---|---|
| Longleaf pine (*Pinus palustris* Mill.). | Heartwood... | 5 | Tangipahoa Parish, La. |
| Douglas fir (*Pseudotsuga taxifolia* (Lam.) Britt.). | Sapwood..... | 13 | Snoqualmic National Forest, Wash. |
| Pacific yew (*Taxus brevifolia* Nutt.). | Heartwood... | ..... | Columbia National Forest, Wash. |
| Mockernut hickory (*Hicoria alba* (L.) Britt.). | Sapwood..... | 6 | Brandywine, Prince Georges County, Md. |
| Beech (*Fagus atropunicea* (Marsh.) Sudw.). | .....do..... | 3 | Do. |
| Red oak (*Quercus rubra* L.). | Heartwood... | 5 | Richland Parish, La. |
| Sugar maple (*Acer saccharum* Marsh.). | Sapwood..... | 11 | Blue Mountain Forest, Newport, N. H. |

The first determinations of density were made on wood sectioned on a microtome; the wood had been previously prepared by boiling in water and soaking in hydrofluoric acid. Subsequently, to avoid possible errors due to this acid treatment, ½-inch cubes of wood were boiled in water until they sank and were then sectioned with a sharp knife.

The results of 21 determinations are summarized in Table II.

[1] Pacific yew was included in response to an urgent demand for data on this species for use in interpreting results secured in the section of wood preservation in the Forest Products Laboratory.

TABLE II.—*Results of 21 determinations, giving density of various species of wood*

| Species of wood. | Density (referred to water at 4° C.). | | |
|---|---|---|---|
| | Soaked in acid at 35° C. | Soaked in water at— | |
| | | 35° C. | 30° C. |
| Longleaf pine | [a]1.6197±0.0007 | ..... | 1.5060 |
| Douglas fir | 1.5915±0.0012 | 1.5698 | 1.5039 |
| Pacific yew | 1.5534 | ..... | ..... |
| Mockernut hickory | 1.5570 | ..... | 1.5525±0.0003 |
| Beech | 1.5929±0.0005 | ..... | 1.4990±0.0002 |
| Red oak | ..... | ..... | 1.5395±0.0004 |
| Sugar maple | 1.6170 | ..... | 1.5506 |

[a] This is not the "probable error;" the mean values in this column rest on only two observations, and the actual deviation of the two from the mean is indicated.

Table II shows, in the first place, that there are significant differences between the densities of the wood substance from various species of trees. The difference between beech and Douglas fir indicates that the extreme range for these seven species is nearly 4½ per cent.

Those sections which had been soaked in hydrofluoric acid as a step in their preparation for sectioning on the microtome showed a higher density than those which were merely boiled in water. It appears that either some constituent with a density less than 1.55 was removed or some foreign substance with a density greater than 1.55 was added to the wood, or else some molecular rearrangement took place in the wood under the influence of the acid. The chemical analysis which might indicate the actual nature of this change was not undertaken.

The table also gives comparable results of determinations on one species at two temperatures, and from these the thermal expansion of wood substance is shown to be negative. This means that wood substance contracts and becomes denser on heating, instead of expanding and becoming lighter in weight. If this is true, wood substance differs from other substances for which records are available. Moreover, it is difficult to reconcile this anomalous behavior with the well-established fact that, in the aggregate, blocks of wood expand when heated.

The observed increase in density between 30° and 35° C. amounts to one-third of 1 per cent, or one-fifteenth of 1 per cent per degree centigrade. This apparent contraction is about twice as large as the expansion which water undergoes between 30° and 35° C.

## APPLICATION OF RESULTS TO THE CALCULATION OF POROSITY OF CROSSTIES

The following data are excerpted from those given on page 48, in Bulletin 126 of the Forest Service, entitled "Experiments in the Preservative Treatment of Red-Oak and Hard-Maple Crossties," by Francis M. Bond:

*General records on the individual ties*

RUEPING—RED OAK

| Track No. | Oven-dry weight per cubic foot. | Absorption per cubic foot. |
|---|---|---|
| | *Pounds.* | *Pounds.* |
| 2 | 37. 14 | 5. 00 |
| 3 | 36. 93 | 5. 46 |
| 4 | 38. 50 | 4. 24 |
| 5 | 40. 30 | 5. 70 |
| 6 | 40. 70 | 4. 26 |

On the basis of these data the portion of the cell cavity occupied by creosote is readily computed, since it is known that the density of the wood substance of red oak is 1.540; its weight per cubic foot is then 96.06 pounds. The weight of the creosote used in these tests is 65.5 pounds per cubic foot. Table III gives the porosity of the individual crossties computed from the foregoing data.

TABLE III.—*Porosity of red-oak crossties*

| Track No. | Oven-dry weight per cubic foot. | Volume of lignocellulose per cubic foot of wood. | Volume of cavity per cubic foot of wood. | Absorption of creosote. | | Percentage of cell cavity occupied by creosote. |
|---|---|---|---|---|---|---|
| | | | | Pounds per cubic foot of wood. | Cubic feet per cubic foot of wood. | |
| | *Pounds.* | *Cubic foot.* | *Cubic foot.* | | | |
| 2..... | 37. 19 | 0. 382 | 0. 618 | 5. 00 | 0. 076 | 12. 3 |
| 3..... | 36. 93 | . 384 | . 616 | 5. 46 | . 088 | 14. 3 |
| 4..... | 38. 50 | . 401 | . 599 | 4. 24 | . 065 | 10. 8 |
| 5..... | 40. 30 | . 420 | . 580 | 5. 70 | . 087 | 15. 0 |
| 6..... | 40. 70 | . 424 | . 576 | 4. 26 | . 065 | 11. 3 |

## SUMMARY

To sum up the results of the investigation:

The density of the wood substance in different species of trees may, for practical purposes, be considered as uniform, with a value of 1.54.

Since most commercial woods have a density between 0.3 and 0.6, it is apparent that the unoccupied space in a block of wood may be from four-fifths to two-fifths of its volume.

# PRELIMINARY AND MINOR PAPERS.

## COMPOSITION OF ROQUEFORT-CHEESE FAT

By JAMES N. CURRIE,
*Chemist, Dairy Division, Bureau of Animal Industry*

### INTRODUCTION

Many of the problems encountered in attempts to produce a cheese of the Roquefort type in this country can be attributed to differences in composition between sheep's milk and cow's milk. These differ not only in the absolute and relative amounts of fat, casein, milk sugar, and ash, but also in the composition of some of these individual constituents. In a recent publication the author (1914, p. 7) [1] attributed the peppery taste of Roquefort cheese to the accumulation during the ripening process of certain volatile fatty acids of the group insoluble or but partially soluble in water. In view of this it seemed desirable to make a comparative study of the fat of cow's milk and the fat of typical imported Roquefort cheese, with special regard to this group of acids.

Roquefort cheese is made chiefly from sheep's milk. The milk supply of the Roquefort-cheese industry is rigidly inspected by agents of the controlling companies for the express purpose of prohibiting the adulteration of sheep's milk. However, the addition of small amounts of cow's milk and also of goat's milk is admitted by the cheese makers. Marre (1906, p. 53) gives the following statistics concerning the milk used in the manufacture of Roquefort cheese for 1904:

TABLE I.—*Statistics of the manufacture of Roquefort cheese in 1904*

| Kind of animal. | Number of animals. | Milk produced. | Proportion of milk. |
|---|---|---|---|
| | | *Hectoliters.* | *Per cent.* |
| Ewes | 521,330 | 329,420 | 97.36 |
| Cows | 1,569 | 8,337 | 2.46 |
| Goats | 699 | 605 | .18 |

For the purpose of this investigation it was thought that a study of the undecomposed fat of typical imported Roquefort cheese would be fully as significant as a study of the fat of sheep's milk, although it is recognized that the two may not be strictly identical.

[1] Bibliographic citations in parentheses refer to "Literature cited," p. 421.

Milk fat is such a complex substance that the exact differences in composition between the milk fats of the various mammals are difficult to determine. That there are marked differences has been shown by Pizzi (1894), who determined the Reichert-Meissl number of the milk fat of 12 mammals. His results are summarized as follows:

TABLE II.—*Reichert-Meissl number of the milk fat of 12 mammals, according to Pizzi*

| Mammal. | Reichert-Meissl number. | Mammal. | Reichert-Meissl number. | Mammal. | Reichert-Meissl number. |
|---|---|---|---|---|---|
| Sheep | 32.89 | Rabbit | 16.06 | Rat | 2.97 |
| Goat | 28.60 | Ass | 13.09 | Sow | 1.65 |
| Cow | 27.00 | Mare | 11.22 | Woman | 1.42 |
| Buffalo | 26.18 | Cat | 4.40 | Dog | 1.21 |

Such differences in the volatile-soluble acids as are shown in the above results suggest differences in the relative proportions of the other acids present.

A thorough search of the literature of the subject has not revealed any report of a complete analysis of sheep's-milk fat. Fodor (1912) determined some of the chemical constants through an entire period of lactation. He obtained the fat by separating it from fresh Liptauer cheese made from sheep's milk. Martin (1914) examined the fat of milk known to be genuine sheep's milk from the locality of Roquefort at weekly intervals from January 28 to June 2. The results of these two investigators, together with the results of Eckles and Shaw (1913) for two breeds of dairy cows, are summarized in Table III.

TABLE III.—*Chemical constants of the fat of sheep's and cow's milk*

| Investigator. | Source of milk fat. | Reichert-Meissl number. | Iodin number. | Saponification number. | Polenske number. | Caprylic-acid number (Dons). |
|---|---|---|---|---|---|---|
| Fodor | Liptauer cheese | 26.84 | 39.3 | 231.5 | ..... | 2.9 |
| Martin | Sheep's milk | 28.48 | ..... | 231.58 | 4.40 | ..... |
| Eckles and Shaw. | Jersey milk | 26.73 | 30.52 | 228.9 | ..... | ..... |
| Do | Holstein milk | 26.28 | 34.20 | 229.1 | ..... | ..... |

The Polenske and caprylic-acid numbers are figures based upon arbitrary procedures and are proportional to the volatile-insoluble acids. Polenske states that his number for a cow's-milk fat having a Reichert-Meissl number of 26 to 27 is 1.9 to 2. Dons gives the caprylic-acid number for cow's-milk fat as 1.75.

From these chemical constants it appears that the quantity of volatile-insoluble acids of sheep's-milk fat is about double that of cow's-milk fat. The oleic-acid content of the former is also greater than that of the latter.

## VOLATILE ACIDS OF ROQUEFORT-CHEESE AND COW'S-MILK FAT

Four Roquefort cheeses of different brands and ripened as little as any to be found in the market were procured and the fat separated by the Schmidt-Bondzynski method. In order to remove any free fatty acids,

the fat was shaken out three times in a separatory funnel with twice its volume of 95 per cent alcohol warm enough to keep the fat in a fluid state. There are certain objections to treating a fat with alcohol (Lewkowitsch, 1909), but this seems to be the only practicable way of removing free acids insoluble in water. The fat was then washed three times with hot water to remove the alcohol, dried, and filtered clear. Fat treated in this way had a decinormal acid number for 10 grams of about 3.0, which is very nearly the same as the acid number of fresh, filtered fat of cow's milk.

The Reichert-Meissl and the Polenske numbers were determined on these four samples of fat and also on a sample of cow's-milk fat, with the following results:

TABLE IV.—*Reichert-Meissl and Polenske numbers of the fats of Roquefort cheese and cow's milk*

| Source of fat. | Reichert-Meissl number. | Polenske number. |
|---|---|---|
| Roquefort cheese: | | |
| Elite | 29.62 | 5.55 |
| Roquefort Belier | 26.72 | 6.25 |
| Mialane et Cie | 26.35 | 5.68 |
| Louis Rigal | 25.64 | 5.60 |
| Cow's-milk fat | 27.27 | 2.00 |

By direct distillation, as in the Reichert-Meissl number determination, only a part of the volatile acids are removed. The total quantity can be more nearly estimated by distillation with steam. Five-gram samples of two of the cheese fats and of the cow's-milk fat were saponified and distilled with steam to 1,000 c. c. The titers of the soluble and insoluble acids are given in Table V.

TABLE V.—*Quantity of soluble and insoluble volatile acids in 5 grams of Roquefort-cheese fat and of cow's-milk fat determined by distillation with steam*

[Expressed in c. c. of N/10 acid.]

| Source of fat. | Soluble acids. | Insoluble acids. |
|---|---|---|
| Roquefort cheese (Elite) | 41.00 | 18.01 |
| Roquefort cheese (Mialane et Cie.) | 38.80 | 19.20 |
| Cow's-milk fat | 36.00 | 11.17 |

The physical properties and also the molecular weights of the insoluble acids showed that an acid of greater molecular weight than capric distilled over with the steam. In order to determine more accurately the quantity of each acid present, the distillate was divided into four fractions. The volatile acids of the first 500 c. c. of distillate constituted fraction 1, and the insoluble acids draining out of the condenser with this 500 c. c. of distillate formed fraction 2. Fraction 3 consisted of the soluble acids of the second 500 c. c. of distillate, and the remainder of the insoluble acids constituted fraction 4. The composition of fraction 1 was determined by a Duclaux distillation, and the compositions of fractions 2, 3, and 4

were determined from the weights of the barium salts and the resulting barium sulphate on moistening with dilute sulphuric acid and igniting. The quantity of each acid in fractions 2, 3, and 4 was estimated by assuming that each consisted of the two acids between which the mean molecular weight of the fraction fell. Only traces of soluble acids distil after the first 1,000 c. c., and the insoluble acids distilling between 1,000 and 1,500 c. c. have a molecular weight greater than that of lauric acid. Hence, it is believed that the first 1,000 c. c. of distillate contains practically all the acids from butyric to capric, inclusive.

By the above process of fractionation the volatile acids of one of the cheese fats (Elite) and of the cow's-milk fat have been estimated. The results are shown in Table VI.

TABLE VI.—*Volatile acids of Roquefort-cheese fat and of cow's-milk fat*

ROQUEFORT-CHEESE FAT

| Fraction No. | $BaSO_4$ from barium salt. | Lauric acid. | | Capric acid. | | Caprylic acid. | | Caproic acid. | | Butyric acid. | | Total acid. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *P. ct.* | *C. c.*[a] | *Gms.* | *C. c.*[a] | *Gms.* | *C. c.*[a] | *Gms.* | *C. c.*[a] | *Gms.* | *C. c.*[a] | *Gms.* | *C. c.*[a] |
| 1 | | | | | | | | 19.02 | 0.2206 | 19.79 | 0.1742 | 38.81 |
| 2 | 47.47 | 1.89 | 0.0378 | 8.63 | 0.1485 | | | | | | | 10.52 |
| 3 | 58.44 | | | | | 2.01 | 0.0289 | 1.37 | .0157 | | | 3.38 |
| 4 | 44.86 | 7.27 | .1454 | 2.43 | .0417 | | | | | | | 9.70 |
| Total | 150.77 | 9.16 | .1832 | 11.06 | .1902 | 2.01 | .0289 | 20.39 | .2363 | 19.79 | .1742 | 62.41 |
| Per cent. | | | | | 3.80 | | .58 | | 4.73 | | 3.48 | |

COW'S-MILK FAT

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | 3.73 | .0537 | 11.20 | .1299 | 22.57 | .2023 | 37.90 |
| 2 | 46.55 | 1.20 | .0240 | 1.70 | .0292 | | | | | | | 2.90 |
| 3 | 55.08 | | | | | 1.63 | .0235 | | | | | 1.63 |
| 4 | 42.53 | 7.69 | .1538 | | | | | | | | | 7.69 |
| Total | | 8.89 | .1778 | 1.70 | .0292 | 5.36 | .0772 | 11.20 | .1299 | 22.57 | .2023 | 50.12 |
| Per cent. | | | | | .58 | | 1.54 | | 2.60 | | 4.05 | |

[a] Acidity expressed in c. c. of N/10 acid.

The butyric acid was also estimated in another of the cheese fats (Mialane et Cie). It contained only 2.99 per cent, which is even less than was shown by the cheese in Table VI. These data show that capric and caproic acids are present in much greater quantities in sheep's-milk fat than in cow's-milk fat.

## SEPARATION OF NONVOLATILE ACIDS OF ROQUEFORT-CHEESE FAT

A fractional separation of the nonvolatile acids of milk fat presents many more difficulties than a separation of the volatile acids. Such a separation involves numerous approximations, but inasmuch as it was deemed desirable to extend the comparative study of the cheese fat and cow's-milk fat to the insoluble-acid portion, the method of Browne (1899) was applied to purified Roquefort-cheese fat.

A sample of 90.29 grams of fat was saponified, washed with 10 liters of water, and separated into seven fractions. The method of Browne was followed, except in some details. Fraction 6 was obtained by

diluting the ammoniacal solution with water as long as a precipitate separated, and fraction 7 by evaporating the entire filtrate from 6, acidifying with sulphuric acid, and extracting with ether. The 90.29 grams of fat yielded 80.8707 grams of insoluble acids, of which 73.5933 were recovered in the seven fractions.

In this process of fractionation the disturbing factor is oleic acid, which not only contaminates every fraction, but also further complicates the problem by giving rise to considerable quantities of dioxystearic acid during the manipulation. From the quantity of oleic acid recovered, which was calculated from the iodin absorption numbers of the several fractions, it was estimated that 23 per cent of the oleic acid was converted to dioxystearic acid. There is a possibility that other unsaturated acids, more readily oxidized than oleic acid, were present, but this problem has not been investigated.

With the foregoing assumptions the composition of the seven fractions was calculated. The results are shown in Table VII.

TABLE VII.—*Weight in grams of the insoluble acids recovered by fractionating 80.8707 grams of insoluble acids of Roquefort-cheese fat*

| Acid. | Fraction No. | | | | | | | Total quantity of acid. |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| Oleic | 4.6893 | 2.2424 | 5.9223 | 0.9262 | 1.3358 | 10.7260 | 1.1558 | 26.9978 |
| Dioxystearic | 1.2101 | .5786 | 1.5281 | .2390 | .3447 | 2.7676 | .2982 | 6.9663 |
| Stearic | 1.7278 | ..... | ..... | ..... | ..... | ..... | ..... | 1.7278 |
| Palmitic | 17.9023 | 3.2793 | 4.4381 | .1412 | ..... | ..... | ..... | 25.7609 |
| Myristic | ..... | 2.0347 | 5.1170 | 1.4832 | 1.6289 | ..... | ..... | 10.2638 |
| Lauric | ..... | ..... | ..... | ..... | .0527 | .0702 | ..... | .7229 |
| Capric | ..... | ..... | ..... | ..... | ..... | .2265 | .9273 | 1.1533 |
| Total | 25.5295 | 8.1350 | 17.0055 | 2.7896 | 3.3621 | 14.3903 | 2.3813 | 73.5933 |

If a correction be made for the oxygen absorbed, the acids not recovered amounted to 7.4045 grams. This loss would obviously consist chiefly of oleic, lauric, and capric acids. The amount of oleic acid was known from the iodin number of the fat, and the capric acid was assumed to be 3.80 per cent of the original fat. The lauric acid could therefore be obtained by difference. The final results, together with the results given by Browne for cow's butter, are summarized in Table VIII.

TABLE VIII.—*Percentage of acids in the fats of Roquefort cheese and cow's milk*

| Acid. | Roquefort cheese. | Cow's milk (Browne). | Acid. | Roquefort cheese. | Cow's milk (Browne). |
|---|---|---|---|---|---|
| | *Per cent.* | *Per cent.* | | *Per cent.* | *Per cent.* |
| Butyric | 3.48 | 5.45 | Myristic | 11.36 | 9.89 |
| Caproic | 4.73 | 2.09 | Palmitic | 28.53 | 38.61 |
| Caprylic | .58 | .49 | Stearic | 1.91 | 1.83 |
| Capric | 3.80 | .32 | Oleic | 38.10 | 32.50 |
| Lauric | 5.84 | 2.57 | Dioxystearic | ..... | 1.00 |

## CONCLUSIONS

The differences between the fat of typical imported Roquefort cheese and the fat of cow's milk are not great enough to warrant the exclusive use of sheep's milk in the manufacture of this type of cheese. However, it is evident that an imported cheese, made wholly or chiefly from sheep's milk, will have more of the peppery taste than a cheese of the same ripeness made from cow's milk.

## LITERATURE CITED

BROWNE, C. A., Jr.
1899. A contribution to the chemistry of butter-fat. *In* Jour. Amer. Chem. Soc., v. 21, no. 10, p. 807–827.

CURRIE, J. N.
1914. Flavor of Roquefort cheese. *In* Jour. Agr. Research, v. 2, no. 1, p. 1–14.

ECKLES, C. H., and SHAW, R. H.
1913. The influence of breed and individuality on the composition and properties of milk. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 156, 27 p.

FODOR, KOLOMAN VON.
1912. Studien ueber die Zusammensetzung des Liptauer Kaesefettes. *In* Ztschr. Untersuch. Nahr. u. Genussmtl., Bd. 24, Heft 4, p. 265–269.

LEWKOWITSCH, J. I.
1909. Chemical Technology and Analysis of Oils, Fats, and Waxes. ed. 4, v. 2, p. 675. London.

MARRE, E.
1906. Le Roquefort. 200 p., illus. Rodez.

MARTIN, M.
1914. La composition des beurres de brebis. *In* Indus. Lait. [Paris], ann. 39, no. 3, p. 55–56.

PIZZI, AUGUSTO.
1894. Comunicazioni varie sulla composizione chimica del 'atte di diversi animali. *In* Staz. Sper. Agr. Ital., v. 26, p. 615–639.

# A NEW SARCOPHAGID PARASITE OF GRASSHOPPERS[1]

By E. O. G. KELLY,

*Entomological Assistant, Cereal and Forage Insect Investigations, Bureau of Entomology*

## INTRODUCTION

On a bright, sunny afternoon early in September, 1908, near Wellington, Kans., the writer noted hundreds of grasshoppers (*Melanoplus differentialis* Thos. and *M. bivittatus* Say) upon tall weeds which grew in abundance along the sides of the road. They were continually flying in front of him, when suddenly his attention was attracted to flies which were striking the grasshoppers, causing the latter to drop to the ground as if shot. Several of the fallen grasshoppers were examined, but no eggs could be found on them, and no attempt was made at that time to rear possible parasites.

On July 31, 1912, the writer caught an individual of *Melanoplus differentialis* as it was being struck by flies, both flies and grasshopper being captured, but, as before, a close examination of the grasshopper indicated that no eggs had been deposited upon it.

The flies, which at first were thought by the writer to be tachinids, were preserved, and the grasshopper, together with four others that had been struck by flies, was caged in an effort to rear the parasites. The grasshoppers died on August 4 and 6. Full-grown maggots issued from these dead grasshoppers on August 10, pupated from August 12 to 14, and adults, identical with those collected on July 31, issued on August 26. These flies were determined by Mr. W. R. Walton, of the Bureau of Entomology, as belonging to several species, one of which has since been determined as undescribed by Dr. J. M. Aldrich. (See description on p. 443–444 as *Sarcophaga kellyi*.) These rearings seemed to furnish ample proof that the species under observation were parasitic, and the writer supposed that in striking the grasshoppers the flies were ovipositing.

The peculiar, quite shrill tone produced by the flying sarcophagids is very characteristic, and being so much louder than that of other flies, it greatly facilitates observations.

## FIELD STUDIES OF SARCOPHAGIDS

On September 17, 1912, a number of grasshoppers, which had been struck by the fly described herein as *Sarcophaga kellyi* Aldrich, were caught and examined closely, but again no eggs could be found on them. A grasshopper upon which no eggs were to be found was then caught and released in the vicinity of five of these flies, all of which were sitting on a block of wood. As soon as the grasshopper was released, the flies darted after and struck it, causing it at once to drop to the ground. It was caught again for examination, but, as before, no eggs could be found upon it. This experiment was repeated several times, always with the same negative results. After this continued fruitless searching for eggs, a number of

[1] Description of new species by Dr. J. M. Aldrich, Entomological Assistant, Cereal and Forage Insect Investigations, Bureau of Entomology.

Journal of Agricultural Research,
Dept. of Agriculture, Washington, D. C.

Vol. II, No. 6
Sept. 21, 1914
K—9

55442°—14——3

the grasshoppers were collected for the purposes of rearing and dissection. Dissection revealed several small maggots in the viscera of the thorax and abdomen and tiny maggots under the scutellum of the metathorax. Flies were then captured and preserved for reference.

On September 19 further investigations of the supposed oviposition of this sarcophagid were undertaken in a different manner. A female fly was caught, and upon dissection the uterus was found to be full of tiny larvæ, indicating that the flies were viviparous. A search was then made on the bodies of grasshoppers for the tiny maggots, and they were readily found on the metathorax, just beneath the scutellum. More critical examinations and observations showed that tiny larvæ were placed by the fly on the underside of the unfolded posterior wings of the flying grasshopper, the striking of the wing by the fly probably causing the sudden dropping of the victim.

A large grasshopper (*Schistocerca americana* Drury) was captured, and when it attempted to fly, while being held by its hind legs, it was at once struck on the underside of the unfolded wing by several sarcophagids. By repeating this experiment in inducing it to attempt flight, the writer was thus afforded opportunity to observe more carefully the larviposition habit of the fly. Several individuals of *Melanoplus atlanis* Riley and *M. femur-rubrum* DeGeer were also collected and the undersides of their wings examined to determine whether this habit of placing the maggots on the underside was usual. On no less than 32 specimens the maggots were found on the underside of the unfolded wing, with a few also placed promiscuously on the abdominal segments. An examination of 75 individuals of *M. bivittatus* gave similar results.

An examination of the folded wing of a grasshopper which had been struck by a fly and suddenly dropped to the ground disclosed the tiny maggots crawling toward the base of the wing, using the sides of the fold for a trough in which to travel. Thus they reach the base of the wing and the metathorax, where the body is quite soft and moist, and enter the body of their victim to feed upon the internal vital organs. They grow rapidly, maturing in from 10 to 30 days. Not all of the maggots, however, are placed on the wing; some are deposited on segments of the abdomen, and these enter through the segmental divisions. After becoming full grown, the larvæ crawl from the body of the grasshopper and enter the soil to a depth of from 2 to 6 inches, pupate, and later emerge as adult flies.

While they are most frequently found beneath the host, the larvæ do not always enter the soil immediately beneath the dead grasshopper, but have sometimes been observed to crawl a distance of 40 inches before descending into the ground.

The sarcophagid larvæ removed from the uterus of the female, as well as those deposited on the grasshoppers, are quite small, tapering from the thoracic segments almost to a point at the posterior extremity. The segments are bordered by a heavy fringe of short, dark bristles or hairs that give the larvæ a banded appearance. The head tapers slightly and is fitted with a pair of toothed hooks that project laterally. The hooks and bristles are used by the maggot in clinging to and working its way into the body of the host. The maggots, soon after entering the host, lose the dark-colored bristles, becoming of a creamy white color and retaining this color until their emergence from the grasshoppers to enter the soil.

A peculiarity of the sarcophagid flies is that they are often unable to distinguish grasshoppers from other insects; they were observed to strike moths and butterflies, actually depositing larvæ upon them. However, attempts to rear the flies from moths and butterflies so attacked were unsuccessful.

While in the midst of these observations a cicada (*Cicada tibicen* L.) flew up, and no less than a dozen flies flew after it. Owing to the exceedingly strong flight of the cicada it could not be captured. The species attacking the cicada could not be determined, but apparently it was *Sarcophaga kellyi*, as this species was the only one collected in the field at that time. The following note by Mr. Theodore Pergande, now in the files of the Bureau of Entomology, indicates, without proving it, that sarcophagids can develop in *C. tibicen*.

On August 22, 1894, Mr. Thomas J. Brady, of Colonial Beach, Va., sent one dead specimen of *Cicada tibicen* to Washington; from it emerged a number of dipterous larvæ, the adults of which have been determined by Dr. Aldrich as *Sarcophaga helicis*.

As further illustrating the indiscriminate deposition by the flies, the writer crumpled a piece of tissue-paper and threw it into the wind among them, when no less than half a dozen flies struck it. When the paper was examined, two tiny maggots were found clinging to it.

In July, 1913, nymphs of *Melanoplus differentialis* and *M. bivittatus* became quite plentiful, affording ample material for study. Adults of *Sarcophaga kellyi* were very common, depositing on nymphs of grasshoppers in the second, third, and fourth instars as they hopped about, but in no instance could a fly be observed depositing on those not in motion.

Mr. H. E. Smith, of the Bureau of Entomology, repeatedly observed flies depositing on nymphs of *Dissosteira longipennis* Thos., on June 16, 1913, during a severe outbreak of this species at Elida, N. Mex. His observations are as follows:

Immediately and for some time after molting, the grasshopper is very soft and by no means active, but crawls upon some vegetation in order to dry. The female sarcophagid flies in amongst weeds, etc., where the grasshoppers are drying themselves, crawls upon them, and though the grasshoppers kick, but not vigorously, sticks living maggots beneath the posterior end of the thoracic sculpture.

Mr. Smith succeeded in collecting enough of the depositing flies to substantiate his observations on the methods of larviposition; and, besides, a large number of *Sarcophaga kellyi* were reared at the Wellington, Kans., laboratory from material collected by him at Elida. Possibly this species in common with others utilizes more than one method of larviposition, thus responding to a variety of stimuli in depositing their young.

Quite a serious outbreak of grasshoppers occurred in the vicinity of Wellston, Okla., early in June, 1913, the prevalent species being *Melanoplus differentialis*, *M. bivittatus*, and *M. atlanis*, with a few scattering individuals of other species, both imagoes and nymphs doing much damage to corn and alfalfa and literally swarming in grasslands. The ground was strewn with dead nymphs and adults of the three species mentioned which had died from parasitism by sarcophagids, their bodies being alive with maggots, while the fields were also literally swarming with these flies engaged in striking adults and nymphs of each instar, except the first, but deposition took place only while grasshoppers were flying, or, in the case of the nymphs, hopping. The winged grasshoppers

appeared to know that the parasites were after them, as when they took wing they made many twists and turns in attempting to get away from the flies. Several adults of *Sarcophaga kellyi* were reared from this Wellston material, while later investigations indicated that the grasshoppers had been materially reduced and practically controlled, so that in late September few eggs were to be found.

## REARING EXPERIMENTS WITH SARCOPHAGIDS

In order to get ample material for study and identification of the species involved, a lot of parasitized grasshoppers were collected and placed in rearing cages. Seventy-two grasshoppers containing a number of these sarcophagid larvæ were collected at the edge of a wheat field on October 21, 1912, and were put in a closed receptacle containing soil; on November 6 following, 97 sarcophagid larvæ were removed from the soil. On December 3, 24 of these pupated and were removed to a receptacle especially designed for rearing Diptera. The remaining 73 larvæ were allowed to continue for hibernation in the soil, which was placed in flowerpots in the laboratory, where they began to pupate on February 3, 1913, adults issuing from the former lot of 24 by the middle of February and from the latter 73 in early March.

On November 8, 1912, 118 living grasshoppers were collected in the same wheat field from which the 72 dead individuals previously mentioned were obtained. Owing to the lateness of the season, these grasshoppers were quite sluggish, but dissection of some of them revealed nearly grown Sarcophaga maggots, as many as 5 to 9 larvæ being removed from some of the grasshoppers. The remaining living grasshoppers were placed in a Riley rearing cage outdoors near the laboratory, but all of them were dead by November 28. The soil of this cage was examined on December 5, and 137 sarcophagid larvæ were removed from it, 75 of these being placed in a large flowerpot and removed to the laboratory, while the remainder were placed in a similar flowerpot which was buried in the soil in the field. These two cages were covered with wire screens. From the indoor cage adults began to issue on February 24, 1913, and continued to issue until May 3. From the flowerpot placed in the field adults began to issue on March 8, continuing to issue until May 5, when the soil was examined and the puparia were all found to be empty.

From the bodies of some 800 dead grasshoppers collected during the fall of 1912 nearly 1,200 Sarcophaga of several species issued. About 800 of these were kept inside in flowerpots and other rearing receptacles, from which adults began to issue about the middle of February, continuing to issue until early May. About 400 of this lot of larvæ were placed in large flowerpots, securely covered, and buried in the soil in the field. An examination of one of these flowerpots in mid-December while the ground was thoroughly frozen indicated that the Sarcophaga were hibernating as larvæ. These larvæ were at once returned to the soil, but unfortunately they were killed by the transfer. Another of these outdoor flowerpots was examined in February. It being then clear that the larvæ had not yet pupated, continued examination until March 8 was made necessary in order that the date of pupation under natural conditions might be learned.

Adults from the flowerpots in the field began to issue in late March and continued emerging until May 28. Comparison of the adults reared

from the Sarcophaga larvæ that issued from grasshoppers collected after death with the adults of Sarcophaga issuing from the living grasshoppers which died in confinement revealed the fact that they were the same species. The indoor and outdoor rearings were indicative of their natural hibernating habits, and subsequent rearings from larvæ from the fields in the spring gave proof of the habit.

## SEASONAL HISTORY AND NUMBER OF GENERATIONS

Observations on the habits of species of Sarcophaga in their relation to grasshoppers were continued in 1913 in the vicinity of Wellington, Kans., beginning with the issuance of the first adults in late April and early May, which was simultaneous with the entering of the second and third instars by the earliest hatched *Melanoplus differentialis* and *M. bivittatus*. At the same time *Chortophaga viridifasciata* DeGeer, a species of grasshopper that hibernates in the nymphal stages, was becoming plentiful in both the adult and nearly grown nymphal forms. The four species, *Sarcophaga kellyi*, *S. cimbicis* Towns., *S. hunteri* Hough, and *S. sarraceniae* Riley, were observed depositing on adults and nymphs of the last species and on the larger nymphs of the other two species, which, however, were not very common. Adults of these four species, which constituted a distinct second generation, began issuing sparingly from these grasshoppers by the first week of June and did not become very much in evidence until about the first week of July, and from this time until November no distinction could be made between generations on account of overlapping. However, judging from the rapidity of their development, there were probably three or four additional generations, making about five or six for the season.

## EFFECT OF POISON ON SARCOPHAGID MAGGOTS

About 200 living grasshoppers that had eaten poisoned bran were collected on October 3, 1913, and by the 17th all had died. Of these grasshoppers 117 contained dead Sarcophaga larvæ and no live ones, as many as 9 larvæ being found in 1 individual. These maggots, with the exception of one which was nearly full grown, were rather small. The use of the poisoned bran in this instance was very effective, for in addition to clearing the field of the grasshoppers it killed the parasites. Poisoned bran was also very effective in the vicinity of Kinsley, Kans.

## OUTBREAKS OF GRASSHOPPERS REDUCED OR CONTROLLED BY SARCOPHAGIDS

The outbreak of *Dissosteira longipennis* in eastern New Mexico, previously mentioned, was considerably reduced by the attack of Sarcophaga larvæ, according to notes made by Mr. H. E. Smith on June 24, 1913, in which he says:

> Found thousands of grasshoppers that had been killed by Sarcophaga larvæ lying dead on the prairie. In some places as many as 15 per square foot were found in this condition.
>
> While in the majority of cases the maggots were still feeding within the bodies of their victims, many full-grown maggots had issued and could be found buried ½ to 2 inches below the surface of the soil.

The investigations by Mr. Smith ended about the 1st of July, and no data as to the results of this parasitism were collected later. Mr. F. R.

Meadows, of American Falls, Idaho, reported on July 22, 1910, that a fly had destroyed the grasshoppers which had been so destructive in that locality during the three preceding years. Unfortunately, specimens of the flies submitted with the letter can not now be located.

Mr. C. B. Neihart, Coulee, Wash., in a letter to Mr. George I. Reeves, of the Bureau of Entomology, dated October 9, 1907, makes the following statement:

> Crops badly injured by grasshoppers; latter now dying by millions. Inclosed specimens collected, some separately, others in bodies of grasshoppers out of which they came after hoppers were put in alcohol. Farmers say that 10 days ago they had no hope of getting crops, but now prospect is good.

Mr. Reeves observed many specimens of *Melanoplus biliturus* Walk. and especially of sarcophagid flies in the fields in a draw at Wilson Creek, Wash., on June 22, 1908. He collected 10 flies, 8 of them having been determined by Dr. Aldrich as *Sarcophaga kellyi* and the other 2 as *S. hunteri*. Mr. Reeves stated that he casually observed one female ovipositing on a Melanoplus, but he unfortunately did not describe the method of the oviposition.

Mr. C. N. Ainslie observed grasshoppers swarming in alfalfa fields in the vicinity of Payson, Utah, in July, 1911. The following note was made by him at that time and is given in full because the flies that he observed have been identified by Dr. Aldrich as *Sarcophaga kellyi* and partially confirm the writer's observations:

> July 16, 1911. While in the vicinity of Payson, 65 miles south of Salt Lake, grasshoppers, mostly immature, were observed swarming in most of the alfalfa fields of that vicinity. Several species appeared to be represented.
>
> In connection with this grasshopper infestation, swarms of flies, large fellows with tessellated abdomens, were everywhere in evidence, being particularly numerous in the vacant spaces in the field that had previously been devastated by the ant, Pogonomyrmex. The numbers of these flies were so great that the hum of their flight was almost equal to that from a swarm of bees. Ten days later in the same locality the grasshoppers were found to be still extremely numerous, both in the stubble and in the alfalfa fields. Swarms of the same species of flies were also observed as on a previous visit. Most of the dead grasshoppers were to be found beneath the alfalfa stems, their bodies being now mere shells, dry and brittle, crushing with the least touch. On digging in the earth beneath some of these dead bodies a number of dipterous puparia were found at depths varying from ½ to 2 inches. The dipterous larvæ, before transforming, seemed to seek damp ground, and in some cases did not descend vertically from the host. In one case a fresh puparium was taken directly from the body of the host, but that was apparently not a common thing.
>
> In one case four large dipterous larvæ were removed from the body of a single grasshopper, two being present in several cases. One crippled grasshopper that could still jump feebly was examined and a small larva was found in its abdomen.
>
> The flies were present in enormous numbers, and as one walked through the alfalfa they would rise in flight, seeming to have unbounded curiosity, and at different times while I was lying on the ground taking notes in the field they would alight on me in large numbers. In several instances as many as from 40 to 50 were counted on my arms and shoulders, resting in the sun. On the wing they are as quick as a flash, as was shown by the manner in which they pursued the winged grasshoppers.
>
> In a stubble field adjoining the alfalfa in which I was making my observations were quite a number of the large-winged grasshoppers (Hippiscus ?) that would take wing as I neared them. In almost every case when one would rise to fly it was pursued by a small swarm of flies; in some cases by as many as a dozen, although the flight was so rapid that nothing more than a guess was possible as to the number of the pursuing flies. The chase was not a mere chance flight, for the flies would mass about the flying grasshopper just as angry bees will gather about one's head in case of pursuit. Dragonflies (Odonata) were not molested in this way, and there seemed to be something in the flight of the grasshoppers that invited pursuit.
>
> August 25, 1911. Studied to-day the grasshopper situation in the same neighborhood as before. Less grasshoppers were present than on July 26. The leafless stems

in the particular field studied had been cut and a new growth had come up that showed little damage. Plenty of dead grasshoppers still lay on the ground beneath the alfalfa, but I could find none that appeared to have recently died. The swarms of flies present in July had diminished somewhat, but many were still on hand. Counted 18 on one arm and shoulder during a brief halt in the field to-day, and noticed repeatedly the same instantaneous dash of these flies for the flying grasshoppers that had been observed before.

It would seem that these parasitic flies have reduced very materially the number of the grasshoppers in this region, but further observation is needed to confirm this—another year.

## SPECIES OF SARCOPHAGA KNOWN TO PARASITIZE GRASSHOPPERS

Several other less abundant species of Sarcophaga were observed in the act of larvipositing on grasshoppers and were subsequently reared from them during these investigations—notably, *Sarcophaga cimbicis*, *S. sarraceniae*, and *S. hunteri*, and in addition to these *S. helicis* Towns. was reared from the dead grasshoppers.

While there are on record many observations strongly indicating that several species of Sarcophaga may be parasitic upon grasshoppers, unfortunately absolute proof as to whether they actually are parasitic upon living grasshoppers or are scavengers feeding upon the dead bodies of grasshoppers has heretofore been wanting. Some of these records are incomplete, through no fault of the observer. As an illustration, Dr. Aldrich stated to the author that he had reared a great number of sarcophagids from grasshoppers at Market Lake, Idaho, during an outbreak in 1898, but unfortunately this material was destroyed by a fire in the University of Idaho, so that no determinations of the material could be made.

Dr. Aldrich has, however, very kindly examined material reared from grasshoppers at Wellington, Kans., and other places, with the result that the following species may now be considered parasitic, having been reared from grasshoppers: *Sarcophaga hunteri* from Payson, Utah, Wilson Creek, Wash., Hamburg, N. Y., and Wellington, Kans.; *S. sarraceniae* from Wellington, Kans., and Washington, D. C.; *S. sinuata* Meig., one specimen from Columbia Cross Roads, Pa.; *S. helicis* from Wellington, Kans.; *S. cimbicis* from Wellington, Kans.; and *S. kellyi* from Wellington, Kans., Washington, D. C., and points in New Mexico, Arizona, and Utah. It appears from the rearings that *S. kellyi* predominates, *S. sarraceniae* being second in abundance according to the material reared from grasshoppers at Wellington, Kans., and the other species occurring rarely.

## REFERENCES IN LITERATURE TO THE HABITS OF SARCOPHAGIDS

Frank Calvert (1882)[1] has reported *Sarcophaga lineata* Fall. as being destructive to locusts in the Dardanelles.

C. V. Riley (1875) has recorded *Sarcophaga carnaria* L. as having been reared from *Melanoplus spretus* Uhl. Dr. Aldrich has shown that this species of Sarcophaga does not occur in North America and that references to it in literature must be referred to another species, or most probably to several native species.

Riley also records rearing sarcophagids from the body of a mantid (Riley, 1875), several species of grasshoppers, and the cotton worm *Alabama* (*Aletia*) *argillacea* Hübn. (Riley, 1885), but was of the opinion that these flies were scavengers.

[1] Bibliographic citations in parentheses refer to "Literature cited," p. 445.

Comstock (1879) reports having reared *Sarcophaga sarraceniae* from *Alabama* (*Aletia*) *argillacea*, and gives some interesting data regarding the biology of the Sarcophagidae.

Coquillett (1892) observed sarcophagids attacking locusts in California during the summer of 1891, and, although he did not succeed in rearing the adult flies, his observations as to the method of attack agree quite closely with those of the writer.

Lugger (1896) observed a species of Sarcophaga, erroneously determined as *S. carnaria*, striking grasshoppers, but erred in stating that it deposited an elongated white egg upon the body of the locust.

S. J. Hunter (1899) has expressed the opinion that species of Sarcophaga which he observed deposited their eggs upon the soft body of the locust immediately after molting had occurred.

H. A. Morgan (1901) has published a list of Sarcophagidae reared from grasshoppers in 1900.

Lahille (1907) states that he has reared a lot of sarcophagids from grasshoppers and thus has recognized them to be parasitic. He did not, however, make any observation on the method of larviposition of the sarcophagids.

Künckel d'Herculais (1893–1905) has described the method of larviposition of *Sarcophaga clathrata* Meigen. His observations were as follows:

> We saw swarms of flies on the ground, flying in the neighborhood of the grasshoppers. We were surprised to see them introducing a tiny larva into the abdominal segments of the grasshoppers (*Stauronotus maroccanus*), but observing patiently and scrupulously they finished the attempt before we were able to seize them. (Translation.)

D'Herculais reared large numbers of *Sarcophaga clathrata* from dead grasshoppers collected in Algiers, and stated that the parasites materially reduced the numbers of the grasshoppers.

It appears from the statements made by the observers quoted herein that sarcophagids have really been known to be parasitic on grasshoppers for a number of years, and yet each of the observers, with the exception of D'Herculais and Lahille, seemed to doubt this fact, on account of the supposedly well-known carrion-feeding habits of the genus. However, the observations by Lugger, Coquillett, and C. N. Ainslie substantiate those of the writer as to the parasitic habit, and if the flies observed by Lugger and Coquillett had been collected they would very likely have proved to be *Sarcophaga kellyi*, since this species predominates in the rearings of Ainslie and the writer.

It is hoped that the facts stated herein will place these species on their correct footing as parasites and will eliminate all doubt as to their habits.

## PARASITES OF THE SARCOPHAGIDS

From the puparia of Sarcophaga were reared *Perilampus hyalinus* Say, only one specimen issuing from each puparium. This species, however, has been fully discussed by H. S. Smith (1912).

*Chalcis coloradensis* Cress. was also reared from a number of the puparia of *Sarcophaga kellyi*, only one adult issuing from each puparium. A few specimens of this species have been collected in eastern Colorado, and on July 27, 1900, Mr. George W. Martin, of Sterling, Colo., sent a number of grasshoppers to Washington which were heavily infested with sarcophagid larvæ. On August 10 adults of *Sarcophaga sarraceniae* issued, and on August 14 two secondary parasites (*Chalcis coloradensis*) issued from puparia of the Sarcophaga.

Several individuals of *Aphaereta* sp. were reared from a few puparia of *Sarcophaga kellyi* at Wellington, Kans., as many as 8 to 12 issuing from each puparium, and several *Eupteromalis* sp. were reared from puparia, the larvæ of which were collected at Dodge City, Kans., in April, 1913. About 10 to 12 adults issued on June 3 from each puparium, and every effort was made to rear them on parasitized grasshoppers, but with negative results.

The Perilampus, Chalcis, and Aphaereta issued during the late winter and early spring of 1913 from puparia in the laboratory under laboratory conditions, and no life-history work could be done on them. Continued observations on grasshoppers during the season of 1913, with special effort toward working out the method and time of oviposition and habits of these hyperparasites, were disappointing; and even a lot of sweepings of crops and weeds where grasshoppers and sarcophagids were very numerous did not reward the writer with a single specimen.

To what extent the parasites of the sarcophagids affect the efficiency of the latter could not be estimated, but it is to be hoped that they never become more than museum rarities.

## DESCRIPTION OF SARCOPHAGA KELLYI

By J. M. Aldrich

**Sarcophaga kellyi**, n. sp. (Pl. XL, fig. 1).

Male.—Front at narrowest about one-fifth as wide as the head (Pl. XL, fig. 2)—average of 10 measured with micrometer and compound microscope is 0.216 mm., the extremes being 0.195 and 0.241 mm.—brownish at vertex, becoming silvery with a slight yellow cast below, the same color extending down the orbit to the lower corner of the eye; frontal stripe dark brown, as wide as one orbit on the upper part; a single pair of vertical bristles (the normal inner pair) inserted somewhat behind the vertex proper (Pl. XL, fig. 3); ocellar bristles normal; frontals ordinary, the upper pair stout and recurved, the lowermost pair inserted toward the eye margin; side of face about half as wide as the median depression, with a few fine hairs in a row next the eye below; antennæ black, third joint about twice the second, reaching two-thirds of the way to the oral margin; arista plumose for more than half its length; vibrissæ slightly above the oral margin, the ridges above them with only a few hairs close down; beard whitish; palpi black; proboscis smallish, retracted.

Thorax (Pl. XL, fig. 1) rather narrow and long, cinereous, slightly ocherous, dorsum with 5 ill-defined subshining black stripes, of which the median one is continued narrowly on the scutellum, and the lateral are abbreviated at both ends; at the front margin another stripe, narrow but distinct, beginning on each side of the median one, but soon disappearing; four postsutural dorsocentrals, the first and second behind the suture smaller than the remaining two, and one or the other of them occasionally represented only by a large hair, but only in rare instances (in the related *Sarcophaga cimbicis* there are three postsutural dorsocentrals, but the anterior one is large and equally spaced with the others); a moderately large pair of prescutellars; acrostichals before the suture about two pairs, rather slender; scutellum with two large bristles on each side, a small apical cruciate pair (absent in two of about 200 specimens examined), and a slightly larger subdiskal pair; notopleurals four, alternating large and small; pleura concolorous with dorsum, three sternopleurals; calypters waxy white, the lower edge with silky whitish hairs; halteres brown.

Abdomen rather narrow, not much curved downward toward apex, yellowish cinereous pollinose, with 3 dorsal blackish ill-defined stripes, most distinct when viewed from behind; segments 1 to 3 with lateral macrochætæ only; segment 4 with a circle of about 16; hypopygium (Pl. XL, fig. 4) moderately prominent, its first segment black in ground color, opaque, with yellowish cinereous pollen, on its apical margin with a row of about 8 very distinct bristles, the row slightly interrupted in the middle; second segment of hypopygium red, with irregular, scattered hairs.

Forceps at base slender, wide apart, yellow, changing to black at about one-fourth the length; at about the middle there is a sudden expansion on the lower inner side (morphologically the dorsomedian), ending in a somewhat recurved point; from this the member tapers very irregularly to the tip. In profile the forceps have an evident

bend dorsad near base. There are numerous stubby, slightly recurved spines on the black part, as shown in Plate XL, figs. 4, 5, and 6. The basal hooklets of the penis are small, not shown in the illustrations; both are recurved at tip, black and approximately equal in length; the posterior has a long hair just before the point on the ventral side; the anterior is wider on the basal half and has a thumblike, sharp point projecting forward, separated from the apical point by a deep incision. The central part of the penis is black and highly chitinized dorsally, prolonged in a pair of slender, upcurved pieces which extend past the softer parts as shown in Plate XL, fig. 4; the ventral soft part consists of two deep irregular folds side by side, without distinct accessory structures or apical lobe.

Legs black; middle tibia on outer front side with two good-sized bristles near the middle; hind tibia on the inner median edge with a sparse row of 8 or 10 fine erect hairs about as long as the tibia is thick, but not villous in any sense, as in some species of Sarcophaga.

Wings hyaline, no infuscation on small cross vein; angle of fourth vein somewhat acute; third vein with a short row of about 7 hairs, first vein bare. Length, 9 to 10 mm.

FEMALE.—More grayish in general color than the male. Head (Pl. XL, fig. 7) wider than that of the male, the front at narrowest (the vertex) one-third as wide as entire head (average of 10 measured with micrometer is 0.339 mm., the extremes being 0.291 and 0.360 mm.); two stout pairs of vertical bristles; two strong orbitals; lower frontals inserted toward the eye margins as in male; palpi much stouter than in male, but ending in a point; scutellum without the small apical pair of bristles; abdomen oval, somewhat tessellated, the three stripes less distinct; fifth segment red, with a row of small bristles at apex from one-half to two-thirds as long as those of the fourth segment; no chitinous ovipositor showing in the many specimens examined. Length, 8.5 to 9.5 mm.

TYPE.—Cat. No. 18250, U. S. National Museum. A male specimen from Wellington, Kans., Webster No. 2250.

MATERIAL EXAMINED.—173 males, 138 females, Wellington, Kans. (Kelly); 62 males, 66 females, Elida, N. Mex. (H. E. Smith); 4 males, Gila River, Ariz. (R. N. Wilson, Webster No. 10535); 2 males, 7 females, Colorado (Hough Coll.); 1 male, 4 females, Wawawai, Wash., reared from grasshoppers in the fall of 1913 by M. A. Yothers, assistant entomologist of the Washington State Agricultural Experiment Station, emerged on September 2 and 13; 3 males, 4 females, Wilson Creek, Wash. (Reeves); 1 male, Payson, Utah, August 11, 1911, reared from grasshoppers (C. N. Ainslie); 13 males, 3 females (Riley's No. 733p);[1] 1 male, 1 female, marked "From *Caloptenus differentialis* Bessey.—*Sarcophaga carnaria*, 174" (referred to in Riley's Seventh Missouri Report, p. 180; reared at Ames, Iowa); 10 males, 1 female (Riley's No. 315a);[2] 2 males, Riley's No. 722p,[3] the label on the pin of one specimen reading "From eggs of *spretus*, Sept. 10, '76," on the other, "Par. on fledged *C. spretus*, sent by Wm. Cutter, Junction City, Kans.—issued Oct. 15, '76"; 4 males, Dallas, Tex., labeled, "From *C. spretus*, May '77, Boll";[4] 3 males, 1 female, Aweme, Manitoba, reared from *Melanoplus atlanis* (N. Criddle), sent by J. D. Tothill.[5]

[1] The notes, still preserved in the Bureau of Entomology, give the following data:
*Sarcophaga sarraceniae* Riley, bred from eggs of *spretus*. Brought by Prof. C. V. Riley from Kansas, Nov. 16, '76, 3 larvæ in a tin box. One larva put in box 8–72. Also from Manhattan, Kans. Box 8–5. Jan. 22, '77. Two of the flies issued. Spread and marked 733p. Jan. 26, '77. Two more issued. There are 8 chrysalids and one larva living yet. Flies spread and marked 733p.

[2] The note on this number is as follows:
Diptera parasite in *Caloptenus spretus*. May 4, 1880. Received to-day from D. D. Sanderson, Whitney P. O., Hill Co., Tex., a box containing parasitized locusts; most of the larvæ had issued on the way and a few had transformed to pupariа; the locusts are perfectly emptied of their contents so that nothing but the hard parts are left. The larvæ are milk-yellow and when stretched to their fullest length measure nearly ¾inch; the surface is granulated and from each of these granules arises a very minute bristle of the color of the body; at the end on upper side of the abdomen is a deep cavity; at the outer edge, each side of the cavity, are 4 fleshy short appendages, the upper pair longest and farthest apart and the lower pair shortest and near together; inside the cavity is a pair of oval spiracles, each of which has 3 longitudinal narrow openings; the edge of the spiracles and of the openings is light brown; these spiracles are situated in the upper wall of the cavity; the anal opening on under [side] is very small and situated between two tubercle-like projections; mandibles black; mounted one larva on slide 1–44–3 and a few are placed into box 4–3; remains of the locusts are placed into box 2.

[3] The entry under 722p in the notes of the former Division of Entomology relates to anthomyiids reared from locust eggs, and could not apply to this second specimen, nor to the first except by misidentification.

[4] Mr. Boll was an agent of the Government in entomological work at that time.

[5] Since preparing this manuscript I have determined specimens of *Sarcophaga hunteri* reared by Prof. A. L. Quaintance from the codling moth, probably from larvæ (Quaintance No. 6908). Heretofore it has been known exclusively as a grasshopper parasite. This is one of the species upon which Mr. Kelly made his observations, and in the light of Prof. Quaintance's record it is evident that these flies do not always deposit their larvæ while on the wing. Therefore both Mr. Kelly's and Mr. Smith's observations (p. 437) were correct.—J. M. A.

The nearest relatives of *Sarcophaga kellyi* are *S. cimbicis* and an undescribed species. *S. cimbicis* differs in having three postsutural dorsocentrals, as above mentioned, and also in having a smaller, wholly red hypopygium; the undescribed species differs in having the rows of frontal bristles not diverging toward the eyes at the lower end (subgenus Ravinia), no small pair of apical scutellar bristles in male, and in having the abdomen in the male strongly arched downward toward the tip.

## LITERATURE CITED


1875. RILEY, C. V. Seventh Annual Report on the Noxious, Beneficial, and other Insects of the State of Missouri ... 196 p., 39 fig., 1 map. Jefferson City.

*Sarcophaga carnaria* reared from *Melanoplus spretus*, p. 180.
*Sarcophaga* sp. reared from body of a mantid, p. 180, footnote.

1879. COMSTOCK, J. H. Report upon Cotton Insects ... 511 p., 3 pl. (2 col.). Washington, D. C.

*Sarcophaga sarraceniae* reared from *Alabama* (*Aletia*) sp. p., 205–208.

1882. CALVERT, FRANK. Sarcophaga lineata destructive to locusts in the Dardanelles. *In* Amer. Nat., v. 16, no. 5, p. 410–411.

1885. RILEY, C. V. Fourth Report of the United States Entomological Commission, being a Revised Edition of Bulletin no. 3, and the Final Report on the Cotton Worm, together with a chapter on the Boll Worm. 399 p. and app. 147 p., 64 pl., 2 maps. Washington, D. C.

*Sarcophaga* sp. reared from (*Aletia*) *Alabama argillacea*, p. 197.

1892. COQUILLETT, D. W. Report on the locust invasion of California in 1891. *In* U. S. Dept. Agr., Div. Ent., Bul. 27, p. 34–57.

*Sarcophaga* sp. attacking locusts in California, p. 49.

1893–1905. KÜNCKEL D'HERCULAIS, J. P. A. Invasions des Acridiens Vulgo Sauterelles en Algerie. t. 1, pt. 2. Alger-Mustapha.

Method of oviposition of *Sarcophaga clathrata* Meigen described, p. 692.

1896. LUGGER, OTTO. First Annual Report of the Entomologist of the State Experiment Station of the University of Minnesota ... for the year 1895. 155 p., 75 fig., 16 pl. Minneapolis.

*Sarcophaga* sp. attacking locusts, p. 57.

1899. HUNTER, S. J. Alfalfa, grasshoppers, oecs: their relationship ... Univ. Kans., Lawrence, Contrib. Ent. Lab. 65, 152 p., 29 fig.

Opinion that *Sarcophaga* sp. deposit eggs on soft body of locust immediately after molting, p. 33.

1901. MORGAN, H. A. The differential grasshopper in the Mississippi Delta—other common species. *In* U. S. Dept. Agr., Div. Ent., Bul. n. s. no. 30, p. 7–33.

List of Sarcophagidae reared from grasshoppers, p. 24–26.

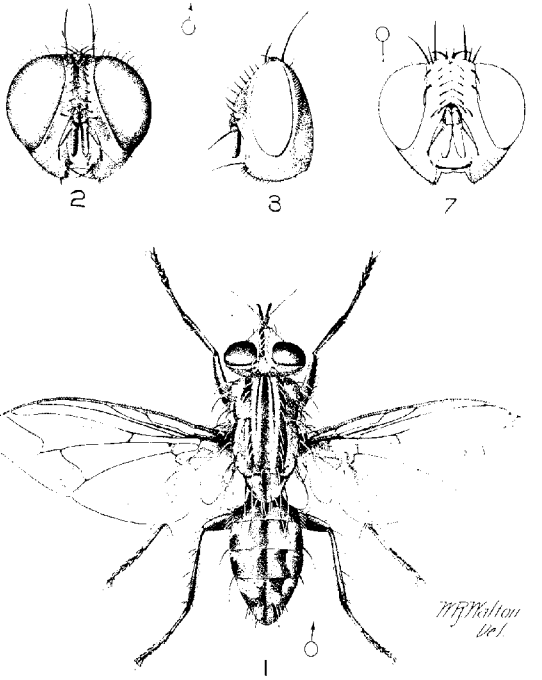
1907. LAHILLE, F. La langosta y sus moscas parasitarias. *In* An. Min. Agr. Argentina, Secc. Zootec., Bact., Vet., y Zool. t. 3, no. 4, 136 p., 29 fig., 7 pl. (5 col.).

Mentions rearing many sarcophagids from grasshoppers, but records no observations on their methods of deposition.

1912. SMITH, H. S. Technical results from the gipsy moth parasite laboratory. IV. The chalcidoid genus Perilampus and its relations to the problem of parasite introduction. U. S. Dept. Agr., Bur. Ent., Tech. Ser. no. 19, pt. 4, p. 33–69, 31 fig.

## PLATE XL

Fig. 1.—*Sarcophaga kellyi:* Adult male fly, dorsal view. Greatly enlarged.
Fig. 2.—*Sarcophaga kellyi:* Head of male, front view.
Fig. 3.—*Sarcophaga kellyi:* Head of male, lateral view.
Fig. 4.—*Sarcophaga kellyi:* Hypopygium of male, lateral view. Greatly enlarged.
Fig. 5.—*Sarcophaga kellyi:* Left half of main forceps of same, ventrolateral view.
Fig. 6.—*Sarcophaga kellyi:* Lateral view of same.
Fig. 7.—*Sarcophaga kellyi:* Head of female, front view. Original.


2
8
7
1
4
5
6

# PAPAYA FRUIT FLY

By FREDERICK KNAB and W. W. YOTHERS,
*Entomological Assistants, Tropical and Subtropical Fruit Insect Investigations, Bureau of Entomology*

## INTRODUCTION

The existence in Florida of a fruit fly peculiar to the papaya (*Carica papaya* L.) was brought to the attention of this department in December, 1905, by the receipt of some fruits of this plant infested with large maggots of an unknown fly. This infested fruit was forwarded by Mr. P. J. Wester, then in charge of the Subtropical Plant Introduction Field Station at Miami. From this material an adult insect was ultimately reared and was determined by the late Mr. D. W. Coquillett as *Toxotrypana curvicauda* Gerstaecker. The papaya not being a plant of special economic importance at that time, no further investigation was made, but in the summer of 1912, Mr. H. M. Russell, an assistant in the Bureau of Entomology stationed at Miami, again reported the presence of maggots in locally grown fruit. In the meantime it had developed that the papaya might reasonably be expected to become an important commercial crop in Florida, and therefore this insect at once assumed an economic importance, in that it presented a serious check to such commercial development.

Infested fruit was again obtained from the Plant Introduction Field Station at Miami through Mr. Edward Simmonds, now in charge of that station, and from this material Mr. E. R. Sasscer, of the Federal Horticultural Board, reared in November, 1912, a single female fly. In the meantime, in October, the junior author had been making field studies of the insect at Miami. Data on its larval habits were obtained, and adults were reared, both from wild and from cultivated papayas. All of this reared material, together with a captured specimen, proved to be *Toxotrypana curvicauda*. The senior author followed up this work in November, 1912, at Miami, and carried the exploration to the Florida Keys and to the Island of New Providence (Bahamas). The habits, life history, and descriptive details given below are based on these studies.

## OLDER RECORDS AND DISTRIBUTION

The specific identity of the papaya fly having been established, an examination of the material of this species and associated references from various sources in the United States National Museum developed several older records.

Probably the earliest specimens received were a set of four sent by Mr. Carlos Wercklé from the town of Santo Domingo in Costa Rica. They bear no date, but are labeled "In fruit of Carica," and were determined by Mr. Coquillett. Under date of July 21, 1910, Dr. P. Osterhout sent the fly from Bocas del Toro, Panama, with the information that it did serious damage there to the fruit of papaya. During September, October, and November, 1910, the fly was reared from larvæ infesting the papaya

Journal of Agricultural Research,
Dept. of Agriculture, Washington, D. C.

Vol. II, No. 6
Sept. 21, 1914
K—10

in Porto Rico, both by Mr. W. V. Tower and by the late Mr. C. W. Hooker, but these specimens were not received for identification until much later. Quite recently a brief account by Hooker (1913)[1] of the occurrence of the papaya fruit fly in Porto Rico and its infestation of the "lechosa," as the papaya is there called, has appeared.

In addition, the fly has been reported, without indication of its habits, from the following localities: Island of St. Jean in the Danish West Indies (Gerstaecker, 1860), erroneously given by Van der Wulp (1898) and Aldrich (1905, p. 600) as "St. John, Antigua"; Brazil (Bigot, 1884); Pebas, Peru (von Röder, 1891); Yucatan (Snow, 1895; Van der Wulp, 1898). It is evident that *Toxotrypana curvicauda* has a very wide distribution in tropical America, probably coextensive with its food plant.[2]

In Florida, Miami appeared to be the northernmost point of distribution at the close of 1912. Examination of cultivated, wild, and semiwild fruit at Little River and in the hammock belt as far north as Arch Creek showed no trace of the larvæ. Recently, in 1914, however, the fly has been reported as very destructive at Palm Beach, considerably farther north. To the south it was found at Key Largo in 1912. Here papayas grow scattered about in cleared land, and the fruit was found infested to a considerable extent. Mature larvæ were obtained from ripe fruit and the imago reared therefrom. Under papaya plants that had been fruiting, puparia or empty pupal shells could always be found. At Marathon, about midway on the Florida Keys, no traces of the fly could be found, although many wild papayas occurred among the wild growth. Conditions farther to the south appeared to be unpromising, and no further search for the fly was made in that direction.

Considerable interest attached to the question whether the papaya fruit fly existed in the near-by Bahama Islands, as it seemed highly probable that it was from there that the fly had found its way to Florida. This point was definitely decided. The Island of New Providence, which lies about 200 miles east of Miami and which is in most frequent communication with the mainland, was visited and the papaya fruit fly located without difficulty. Adults were reared from some of the larvæ and puparia obtained on this island, which precludes all doubt as to the identity of the pest.

## DESCRIPTION OF PAPAYA FRUIT FLY

### THE ADULT

The papaya fruit fly (*Toxotrypana curvicauda*) belongs to the dipterous family Trypetidae and exhibits a certain superficial resemblance to a common brown wasp (Polistes). This is due not only to its similarity of size, form, and general coloration, but in life this is accentuated by the manner in which it walks about on the fruit, with its body well elevated upon its slender legs, and by a certain nervousness of movement. The female is remarkable for its long and slender curved ovipositor, which exceeds the length of its body.

FEMALE (Pl. XLI, fig. 1).—Yellow and brown, marked with black. Head broad, fully as wide as the thorax at wing base, inserted upon a slender prothoracic neck; eyes elongate, subovate, prominent, bulging at the sides, separated by about their own

[1] Bibliographic citations in parentheses refer to "Literature cited," p. 453.

[2] The papaya is a native of tropical America and is now cultivated for its fruit throughout the Tropics of both hemispheres. Its introduction into Florida is probably comparatively recent, although no data bearing on this point are available, and the wild plants in southern Florida and the adjacent keys are seedlings from such introduced plants.

width; occiput, frons, face, and cheeks yellow, a black transverse patch at the ocellar triangle, a diffuse smoky patch over insertion of antennæ and another along oral margin; and a black spot crossing cheeks from lowest part of eye; antennæ piceous or dull ferruginous, the third joint elongate, rounded at apex, the arista inserted close to its base, nearly twice as long as the joint, very slender, with very fine ciliation; proboscis and palpi black. Thorax convex, broadest at wing base, narrowed anteriorly, yellow, with a ferruginous shade on the disk, the mesonotum with several pairs of abbreviated blackish stripes and a transverse spot in front of the scutellum, the pleuræ with three irregular, transverse, blackish bars; scutellum yellow, with sharp black lateral angles; postnotum ferruginous and black. Abdomen pedunculate, with six well-defined segments, of which the second is much the longest; venter channeled at the sides; colors yellow and dull brown, with dark diffuse bands at apex of first, middle of second, and bases of the following segments; ovipositor longer than the body, slender, cylindrical, strongly curved, thickened basally, ferruginous. Legs slender, rather long; femora yellow, ferruginous at bases and apices and with a dark oblique band near middle; tibiæ yellow and ferruginous, the anterior pair darker; tarsi ferruginous, shading to brown, densely pubescent. Wings long, rather narrow, rounded at apex, all the cells much elongated; second vein with an angulation or loop opposite the end of the first vein and usually just beyond this with a slighter one, which in many specimens sends out at right angles a spur toward the costa; last section of the fourth vein sinuate; lower end of posterior cross vein close to wing margin; anal cell with the lower angle drawn out very long and narrowly; colors hyaline and ferruginous yellow, the yellowish color involving the anterior region to the second basal cell and the anterior portions of the first basal and first posterior cells, as well as the anal and the base of the third posterior cell. Length: Body, exclusive of ovipositor, 8.5 to 12 mm.; ovipositor (measured in a straight line from base to tip) 9 to 13 mm.; wing, 8.5 to 12.5 mm.

MALE (Pl. XLI, fig. 2).—Closely resembles the female in coloration and general appearance, without the ovipositor. The abdomen is pedunculate and blunt at the tip, less distinctly banded than in the female and more hairy; the frons is slightly wider; the spur of the second vein usually joins the costa, and shortly before this there is often in addition a short spur projecting into the submarginal cell. Length: Body, 11 to 13.5 mm.; wing, 8.5 to 11 mm.

## THE EGG

The eggs (Pl. XLII, fig. 1) are of very unusual shape. They are very long and slender, fusiform in the micropylar half, the opposite half drawn out into a cylindrical stalk. The length of the entire egg is from 2.55 to 2.75 mm., the greatest diameter 0.18 to 0.2 mm., the diameter of the attenuated portion 0.06 to 0.07 mm. The surface is smooth, without reticulation or sculpture.

The eggs were procured from gravid females by dissection. The number of eggs produced by a single female appears to be slightly in excess of 100; the counts from two females, both showing a distended abdomen and probably containing a nearly full complement of eggs, gave 103 fully developed eggs in each case. No eggs in process of development were present, which indicates that all the eggs are disposed of within a short period.

## THE LARVA

The larvæ (Pl. XLII, fig. 2) are shining, dirty greenish white in color while feeding upon the interior seed mass. Larvæ that have matured within the ripened fruit and that have penetrated into the meat are the same rich golden-yellow color as the ripe fruit.

Form moderately stout, subcylindrical, tapered anteriorly to the mouth, highly polished; head segment closely transversely striate beneath, mouth hooks blunt, well separated; anterior spiracles with about 25 lobes; body segments nearly smooth above, ventrally with a transverse callosity at the anterior margin, beyond the third segment also with a callosity at the posterior margin, the surface of these callosities with numerous, irregular, transverse, raised, punctate striæ, segments beyond the third also with a deep median transverse impression; posterior end truncate, the stigmatal area slightly depressed, surrounded by a groove; stigmatal plates small, separated by about their own width, each with three transverse, straight slits, slightly diverging outwardly; anal tubercles small, upon a swelling bordered by two callosities.

THE PUPARIUM

Puparium (Pl. XLII, fig. 3) of the usual stout subcylindrical form, with rounded ends; slightly depressed ventrally, the larval callosities obsolete; laterally with a series of shallow longitudinal impressions; stigmatal area hardly differentiated; anal papillæ prominent; color ferruginous yellow to light ferruginous.

## HABITS OF THE LARVÆ

The papaya fruit-fly larvæ occur in the interior of the fruit, first feeding in the central seed mass, but later, as they mature and the fruit ripens, working into the meat and ruining the fruit (Pl. XLII, fig. 4). The number of larvæ in a single fruit varies from 2 or 3 to 20 or more. Sometimes larvæ of different sizes occur within the same fruit, showing that the infestation was from more than one oviposition.

The cultivated fruit in the Subtropical Field Station at Miami was by no means so generally infested as the wild fruit in the hammock south of it. Evidently infestation stood in relation to the thickness of the meat of the fruit, in that cultivated forms having the thickest meat were least affected. Several of the latter, some still small and others nearly ripe, were cut open, and no maggots could be found. The only evidences of injury to these thick-meated fruits were numerous scars that had the appearance of egg punctures. On the other hand, the fruit of volunteer plants in the Field Station, with thin meat and large seed cavity, was frequently infested.

The wild fruit in the hammock [1] was found to be very badly infested with papaya fruit-fly larvæ. This wild fruit is very small and seldom exceeds 2 inches in diameter. The meat is thin, and there is comparatively little flow of juice when the surface is injured.

To determine the amount of infestation in the wild fruits of different sizes or ages, an examination was made of small fruits about three-fourths of an inch in diameter, medium-sized fruits, and large ripe fruits. Out of 208 small fruits, 41 showed infestation, and 167, or 80 per cent, were sound. Out of 52 medium-sized fruits 26, or 50 per cent, were free from infestation. Examination of 25 nearly ripe fruits showed that none were sound. Again, in a miscellaneous lot of 63 fruits, 32, or over 50 per cent, were infested. In general, small or young fruit is much less infested than the older fruit, the flies evidently selecting the larger and more mature fruits for oviposition.

A remarkable fact was the occurrence of dead full-grown larvæ in fruits externally sound. In the 208 small fruits, 33 living and 3 dead larvæ were found. In the 52 medium-sized fruits there were 22 living larvæ and 1 dead larva. In the miscellaneous lot of 63 fruits there were 82 living larvæ and 38 dead ones. In the 25 nearly ripe fruits, however, the dead larvæ exceeded the living ones, there being 12 of the former and 6 of the latter. The importance of these data will be discussed farther on.

It was found that contact with the juice of the unripe fruit is quickly fatal to the larvæ, which explains the presence of the dead larvæ in

[1] In the hammock, the virgin tropical vegetation to the south of Miami, papaya plants were growing adventitiously in large numbers, particularly along the edges of the hammock and in the more open spots. The abundance of these wild papayas was traceable to the operations of real-estate men, who, about a year earlier, cleared the trees and shrubs from a portion of the hammock to lay out streets. In these cleared places the papaya had sprung up in great profusion. On the authority of Mr. W. E. Safford, of the Bureau of Plant Industry, wherever the papaya is grown wild plants very quickly spring up adventitiously in the vicinity, particularly in newly cleared land. Undoubtedly the seeds are distributed through the agency of birds, and in this way the plants make their appearance at a distance from the point of cultivation.

unripe fruit. These dead larvæ are always full grown and therefore perished at the time that they would have normally made their escape from the fruit, in order to pupate in the ground. In ripe fruit mature larvæ are easily able to bore out through the soft meat, which then no longer exudes the gummy juice characteristic of unripe fruit; but the sticky exudation of the flesh and rind of unripe fruit is fatal to the larvæ, probably by asphyxiation.

## PUPAL PERIOD

The larvæ, when about to pupate, usually leave the fruit as just described and fall to the ground. The pupal period is passed either under some fragment of coral rock or in the soil at a depth of 1 or, at the most, 2 inches below the surface. Rarely puparia were found within the hanging fruit. The pupal period varies according to the meteorological conditions. In Porto Rico, Hooker (1913), found that the duration of the pupal period was from 17 to 21 days. The observations of the authors, made in the cool season of the year, showed a pupal period of from 30 to 42 days. They further show that moisture conditions, as well as those of temperature, affect the length of the pupal period, and that excessive dryness has a retarding effect and if prolonged may prove fatal.

## HABITS OF THE ADULT FLY AND OVIPOSITION

Special effort was made to learn something of the habits of the adult fly. The senior author, while at Miami, made frequent visits to the papaya plantation at the Subtropical Plant Introduction Field Station and to the hammock south of it, with this object in view. Careful watching in the vicinity of the papaya plants, and vigorous searches were alike unsuccessful until near the close of the investigation. It was then found that the flies are only active for a very short period just before sunset.

About half an hour before sunset a female papaya fruit fly came with rapid flight and alighted unhesitatingly upon a well-developed but green papaya. After walking about a little on the top of the fruit, the fly began to insert its long ovipositor, and in a remarkably short time had sunk it full length into the fruit. As soon as the fruit was punctured the milklike liquid, which the unripe fruit exudes wherever injured, welled forth and began to trickle down the side. The fly very soon withdrew its ovipositor and was about to take wing when it was captured. In the course of about 15 minutes some eight or more flies were seen, all behaving in the manner described, and four of these were captured in the act of puncturing the fruit. The next evening, in the same place, a few more female flies were seen at about the same time, but none earlier and none later. It seems evident that flight and oviposition occur at a definite time in the evening, a little before sunset, and are governed by the amount of light. Under the conditions observed, viz, on bright, nearly cloudless days, this activity does not last more than 15 or 20 minutes. There may also be a morning flight, for Mr. Simmonds stated that he had captured the fly early in the morning.

It is evident that the female endeavors to thrust her ovipositor through the meat of the fruit to deposit her eggs in the central seed chamber, and it is only in the varieties with thinner meat that she can succeed. With the exception of mature larvæ in ripe fruit, the larvæ are always found within the seed mass. It is only when they are full grown, or

nearly so, that they enter the meat, work their way out, and drop to the ground, in order to pupate just beneath the soil. As already pointed out, the juice from the injured meat of the unripe fruit is fatal to the larvæ; therefore the eggs must be placed beyond it in the seed chamber.

Later observations were made by Mr. C. A. Mosier, of Little River, Fla., who has had many opportunities to observe the papaya fruit fly. He recently forwarded the following notes on its habits:

> The flies do not oviposit on very young fruit, but are found more on large to full-grown fruit. One female was captured with the ovipositor fully embedded in three-fourths ripe fruit. I also noted that the flies skipped deformed and gnarled fruit. More females are out on dark cloudy days, while the males are active and predominate on warm sunny days and are sluggish on dull days.
>
> Also, I have found three females dead, or nearly so, that had been trapped by the juice of the fruit coagulating before the ovipositor was withdrawn.

## PAPAYA FRUIT FLY RESTRICTED TO THE PAPAYA

The fact that in a fruit-growing section like southern Florida no complaints of infestation of fruits other than the papaya had been made was in itself evidence that the pest is peculiar to this fruit. This was confirmed by examination of other fruits and by transfer experiments. Immature larvæ transferred to citrous fruits failed to complete their transformation and died.

## RAPID INCREASE OF THE FRUIT FLY

During the last two years, more particularly as a result of the increased cultivation of the papaya in southern Florida, this fruit fly has also rapidly increased and extended its range so as to seriously threaten the future development of the papaya industry. Some varieties of Philippine stock producing large fruit grown at Lemon City, Fla., are apparently free from attack. A very fine large variety of fruit grown at Lemon City, Fla., from Philippine stock was found to be free from the larvæ.

## CONTROL

It has been pointed out that fruit with very thick meat escapes infestation. While the papaya fruit fly attempts to oviposit on such fruit, the thickness of the meat prevents the tip of the ovipositor from reaching the seed cavity, and in the meat itself the larvæ can not live. It was further found that in some fruits the larvæ had reached maturity before these had ripened and had been killed by the sticky juice of the green fruit in endeavoring to escape. The means of control that now seem valuable are the production of varieties of papaya that have thick meat and that ripen slowly, and the conscientious destruction of adventitious or wild papaya plants and of all infested fruits. All plants with inferior fruit should be eliminated.

## LITERATURE CITED

1860. GERSTAECKER, A. Beschreibung einiger ausgezeichneten neuen Dipteren aus der Familie Muscariae. *In* [Ent. Ztg. Stettin] Jahrg. 21, No. 46, p. 193–202, pl. 2.

"*Toxotrypana curvicauda*," p. 194–195. Original description.

1884. BIGOT, J. M. F. [La description d'un nouveau genre et d'une nouvelle espèce de Diptères de la famille des Ortalidæ.] *In* Ann. Soc. Ent. France, s. 6, t. 4, pt. 2, Bul. Seances, p. XXIX–XXX.

Male described under the name "*Mikimyia fasciata*."

1891. RÖDER, VICTOR VON. Bemerkungen zu dem dipterologischen Beitrage von Prof. Mik in der Wiener Entomologischen Zeitung, Jahrg. 1890, pag. 251, über Toxotrypana curvicauda Gerst. *In* Wien. Ent. Ztg., Jahrg. 10, Heft 1, p. 31–32.

1895. SNOW, W. A. On Toxotrypana of Gerstæcker. *In* Kans. Univ. Quart., v. 4, no. 2, p. 117–119, 1 fig.

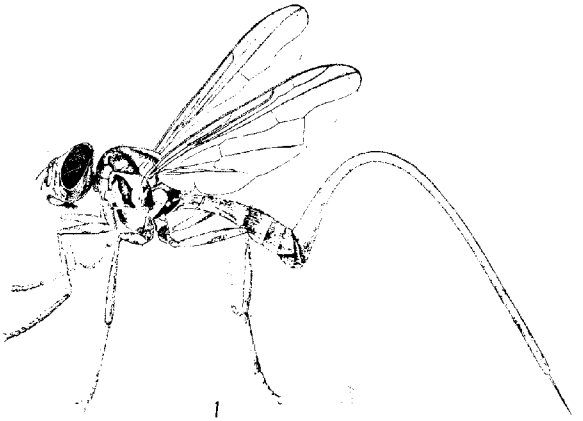
1898. WULP, F. M. VAN DER. Biologia Centrali-Americana. Insecta. Diptera. v. 2, p. 379, tab. 10, fig. 2, 2a. London.

1905. ALDRICH, J. M. A Catalogue of North American Diptera (or Two-Winged Flies). 680 p. Washington, D. C. (Smithsn. Misc. Coll., v. 46, no. 1444.)

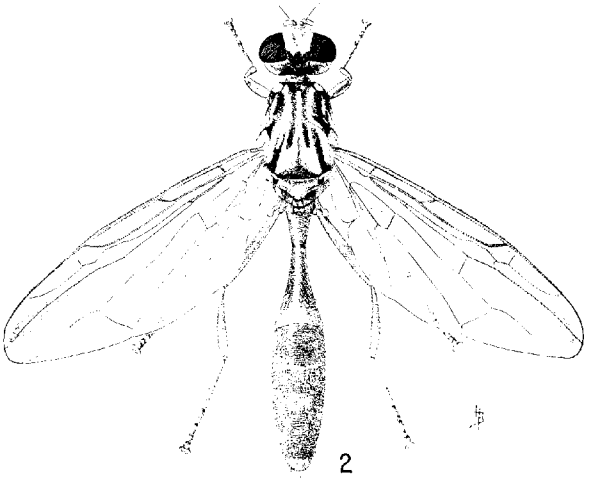
1913. HOOKER, C. W. Fruit flies. *In* Porto Rico Agr. Exp. Sta. Ann. Rpt., 1912, p. 36.

PLATE XLI

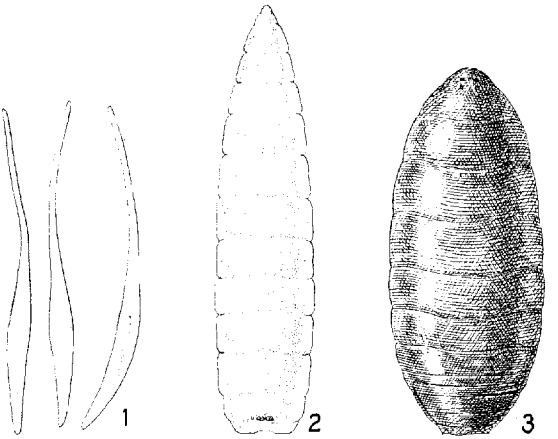
Fig. 1.—*Toxotrypana curvicauda* Gerst.: Female. Enlarged.
Fig. 2.—*Toxotrypana curvicauda* Gerst.: Male. Enlarged.



1



2


1
2
3

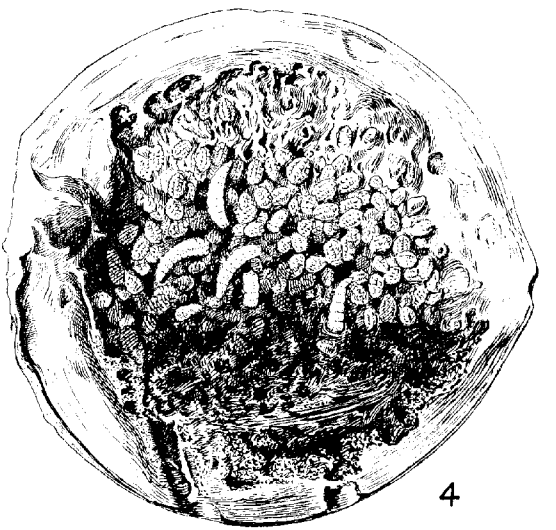

4

PLATE XLII

Fig. 1.—*Toxotrypana curvicauda* Gerst.: Eggs. Enlarged.
Fig. 2.—*Toxotrypana curvicauda* Gerst.: Larva. Enlarged.
Fig. 3.—*Toxotrypana curvicauda* Gerst.: Puparium. Enlarged.
Fig. 4.—Papaya fruit infested with larvæ of *Toxotrypana curvicauda* Gerst. Somewhat reduced.

# INDEX